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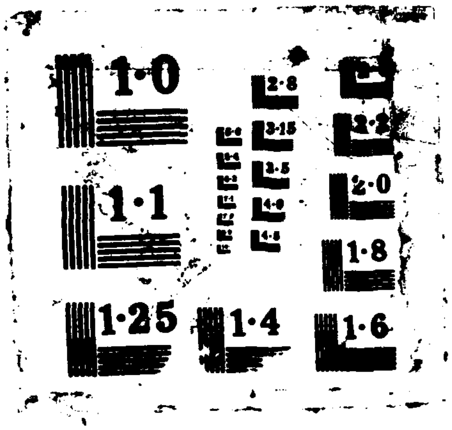
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MODELING THE EFFECT OF SPARE PARTS LATERAL RESUPPLY ON STRATEGIC AIRLIFT CAPABILITY

THESIS

William J. Carolan
Captain, USAF

AFIT/GOR/ENS/86D-2

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MODELING THE EFFECT OF SPARE PARTS LATERAL RESUPPLY ON STATEGIC AIRLIFT CAPABILITY

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Operations Research

William J. Carolan, M.S.
Captain, USAF

December 1986

Approved for Public release; distribution unlimited

ABSTRACT

The objective of this thesis is to develop and analyze a 2-echelon resupply system in which inter-site movement of recoverable spare parts within the same echelon are permitted. The Military Airlift Command (MAC) of the U.S. Air Force is a prime user of this system, where spare parts are transferred between overseas bases for the purpose of expediting aircraft repairs, and enhancing airlift capability.

Existing inventory models do not explicitly account for lateral resupply, thus underestimating MAC's actual capabilities. The significance of omitting lateral resupply, when in fact it exists, is largely conjecture. This paper attempts to analyze this significance.

The Simulation Language of Alternative Modeling (SLAM) was used to model a realistic strategic airlift wartime scenario to evaluate the system during a surge of flying activity. The Statistical Analysis System (SAS) provided the statistical procedures to test for the significance of a lateral resupply policy.

Incorporating lateral resupply in a spare parts supply model can aid strategic airlift planners in assessing the Command's readiness and sustainability.

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The objective of this thesis is to develop and analyze a 2-echelon resupply system in which inter-site movement of recoverable spare parts within the same echelon are permitted. The Military Airlift Command (MAC) of the U.S. Air Force is a prime user of this system, where spares are transferred between overseas bases for the purpose of expediting aircraft repairs, and enhancing airlift capability.

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PREFACE

Incorporating lateral resupply in a spare parts capability assessment model is a current topic of concern to the Military Airlift Command (MAC). Several organizations including RAND, Logistics Management Institute, and Headquarters Air Force Logistics Command, are working on ways to satisfy MAC's need. This thesis analyzes the significance of lateral resupply, and offers a possible solution in the form of a simulation model.

I wish to thank many people for their contributions to this research effort. The original idea for this thesis came from two sources, Major Christensen from HQ MAC/LGSWR and Mike Niklas from HQ AFLC/XRSA, who provided valuable assistance in formulating the problem. Mrs. Dee Caumiant, also from MAC/LGSWR, provided the needed data, and cheerfully answered the many questions I had.

A special thanks goes to my thesis advisor, Major Joseph Litko, whose knowlege and wisdom kept me on track. He was always available to help with any problems I encountered.

Last, but not least, this thesis could not have come to fruition without the understanding and patience of my wife Jacki.

William J. Carolan

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VI. Conclusions and Recommendations

Conclusions

A simulation model, written in SLAM, provided the means to analyze a realistic strategic airlift wartime scenario. Aircraft parts data came from the WRSK kit of the C-141, and an actual wartime scenario used by MAC planners represented an expected 30-day surge of flying activity. The mean percentage of planes FMC during the 30 days was selected as a measure of performance. The spare parts repair and replace processes were modeled both with and without lateral resupply to test the effects of such a policy. Lateral resupply was determined to be a significant factor in measuring strategic airlift capability.

The second research question posed in chapter I was "Can a model be developed for use by HQ MAC logisticians to accurately measure MAC's wartime airlift capability relevant to spare parts stockages?" Due to the dynamic and complex network of MAC operations, simulation seems the best approach to measuring their capability based on availability of spares. SLAM is a good choice for the simulation language since MAC already has the software installed, and the spare parts model can be integrated into their M-14 SLAM model if desired.

The procedure of lateral supply is a major factor that must be reckoned with if valid assessments are to be made. An assessment tool that does not explicitly model lateral resupply will underestimate MAC's true capability. This

thesis presents one workable model for this purpose. However, this model does take a very detailed look at a scenario, and perhaps some areas can be simplified to make the model easier to use. On the other hand, enhancements can be added to the model to increase its accuracy. Suggestions for further research are discussed next.

Recommendations

Continuing efforts should be made to find a good model for assessing MAC's strategic airlift capability based on spares availability. Lateral resupply is one aspect that must be included in such a model. Also, varying flight times should be used to represent the different sortie lengths flown by MAC aircraft. The idea presented in this paper of using actual scenario sortie lengths seems a logical and accurate way of accomplishing this. For simplicity, perhaps each base in a scenario could be assigned a mean sortie length based on probable flights into that base. Scenarios could then be easily modified since the only variable would be the number of flights into each base.

Probably the biggest improvement that can be made to the model in this paper would be a simpler way of determining lateral resupply times. As it stands, every time a base is added to or subtracted from the scenario, a new matrix needs to be constructed of lateral shipping times. Simply taking an average shipping time from a particular region is one possibility, but a determination still must be made as to which base will supply the part. An in-depth study of the

lateral resupply procedure might suggest an accurate and simple way to handle this problem.

Two enhancements that would make the model more realistic are cannibalization procedures and the addition of another echelon represented by a central intermediate repair facility (CIRF). An analysis of different cannibalization policies, and their effects on airlift capability could be a thesis in itself. Cannibalization is an area that requires extensive research to formulate accurate and workable policies. The addition of a CIRF does not appear to be anything more than an extension of the same principles used in the research model, just an additional base storing and repairing parts at an overseas location.

APPENDIX A: MODEL DESCRIPTION

Network

Flight Times for Lateral Resupply. These times represent the minimum flight times between bases in the scenario. They are input to a 25 X 25 array, with the row representing the "from" base, and the column representing the "to" base. Where times differ slightly between two bases flying in opposite directions, the difference is due to winds aloft. Generally, flying east is quicker than flying west. Where enroute stops are necessary, a ground time of two hours is used.

Plane Creations and Routings. Each plane flying the scenario was created at a time based on a zero reference line of time 0001 on the first day of the scenario. The first plane created was plane #9, created at time 20, which would be a takeoff time of 2000 on day 1. Planes were numbered starting from 52, in the order they were listed in the flow plan. An attribute is assigned to each plane corresponding to the row number of the first sortie the plane is scheduled to fly on the sortie data file. This attribute (R) is incremented after each successful stop, so the next mission can be flown.

When the first plane (#9) was created, the subroutine PARTS was called, which distributed WRSK parts among the planes and bases.

NMCS Queue. A file (#94) holding parts sent to the depot represents depot repair, where the number of servers can be specified. Using Palm's theorem, the number of servers was set at 100, representing unlimited repair capability. With this assumption, parts never need to wait for repair. If a situation arises where the number of servers is known, a different number can be inserted. Repair time at the depot is assumed to be the same as for the base repair shop.

Following repair, event 9 is called, which adds one to the stock quantity for that part. This represents the fixed part being placed into depot stock.

Assigning Plane Attributes. Each plane acquires new attributes of hours flown (HRS), arrival base (BASE), and ground time (GND) for each sortie flown. The HRS is used in another subroutine (CHECK) to calculate part failures.

BASE is used to keep track of which base needs a certain part, and to place planes in queues at those bases until a part becomes available. Queues are numbered as the base number plus 25.

GND is used to advance the clock, so a plane can fly its next mission. The ground time for each planes's last sortie is a zero in the sortie data, so that a plane can terminate after it finds its GND to be zero.

Taxi. Taxi time is a constant set at 15 minutes (.25 hours) in the initialization subroutine (INTLC).

Fortran Subroutines

There are nine subroutines written in fortran, in addition to a subroutine EVENT which triggers one of the nine, an initialization subroutine (INTLC), which is called by SLAM at the beginning of a simulation run, and subroutine OTPUT, which is called by SLAM at the end of a simulation run. Each subroutine will be discussed in the order they appear in program code.

PARTS. This subroutine distributes WRSK parts to the bases and planes. The 236 parts are in file 51, along with each part's attributes, so the parts are copied from that file the number of times corresponding to the correct quantity of the part.

Each of the five C-141 bases receives a WRSK complement of parts. For the West coast bases, McChord, Travis, and Norton give up their AA segments to the Korean bases, Osan, Pohang, and Yechon. The East coast C-141 bases, Charleston and McGuire, receive their full WRSK.

The FSL overseas bases receive the equivalent of a TB segment, and each aircraft receives one of each type part.

CHECK. This subroutine checks to see if any aircraft parts have broken during a plane's last sortie. When a plane lands, each part is removed one by one, and the formula

$$\text{Prob}(F) = 1 - e^{-\lambda t}$$

where = part demand rate

and t = sortie length

is used to determine if a part has failed. Prob(F) is

compared against a randomly drawn number, and if the draw is less than Prob(F), a failure is said to have occurred.

The failed part is placed into a repair file (97), so that the part's attributes can be saved, and subroutine REPAIR is scheduled to commence immediately. If the draw is greater than Prob(F), the part is put back on the plane. Multiple part failures can occur.

A check is made to see if a plane has all its parts (it will if none have failed), and if so, the plane reenters the network to fly its next sortie.

REPAIR. This subroutine determines whether a failed part will be repaired locally (base repair) or sent to the depot. Each part has a probability of base repair as its third attribute. A randomly drawn number is compared against this probability, and if the random number is less, a check is made to see if the current base has repair facilities. Only PSP and FSL bases have base repair. If the part can be repaired locally, the base repair subroutine (BREPAIR) is scheduled to occur after the repair time has elapsed. Part attributes are stored in file 93.

If the part cannot be repaired locally, it is sent to the depot, where subroutine depot repair is scheduled to occur after a constant shipping time (2 days) has elapsed. Part attributes for depot repair are stored in file 95.

When a part is sent to the depot, a replacement part is ordered from the depot. Subroutine DEPORDER is scheduled to occur after a constant OST has elapsed. Part attributes are stored in file 98.

Accompanying the repair process, a search process is scheduled to begin immediately to locate the most accessible replacement part.

DREPAIR. This subroutine occurs after the depot ship time has elapsed. It removes the part from file 95 and puts the part into the depot repair queue (file 94) at the depot. The depot repair queue was discussed earlier in the Network portion of this appendix.

BREPAIR. This subroutine occurs after repair time for the part has elapsed. The part is removed from the repair file, and placed into base stock, signifying a completed repair cycle. Next, a check is made to see if there is a plane in the NMCS queue at that base in need of the part. If the part is found to be missing from a plane in the queue, the part that just came out of base repair is put on the plane. If the plane has all its parts, it enters back into the Network to fly its next sortie.

SEARCH. This subroutine looks for the fastest means to acquire a replacement part. The lateral resupply procedures are incorporated in this subroutine.

First, a check of base stock is made. If the part is in base stock, it is immediately removed and put on the plane. The plane leaves the subroutine, and if it has all its parts, it enters back into the Network to fly the next sortie. No delay is incurred for the plane, since it is assumed that the procedure can take place during the normally scheduled ground time.

If the part is not in base stock, the lateral resupply process begins by finding all bases which have the part in stock. Of those bases, the closest base (in terms of flying time) is selected. If the lateral supply time (LST) is less than base repair time (if the part went to base repair), or OST (if the part was ordered from the depot), then subroutine LATSUPPLY is scheduled to occur LST hours later. Part attributes are stored in file 96, by least value first, so the correct part will be identified when the subroutine is called. The plane is put into an NMCS queue at the base, where it waits for the first available part that it needs. The needed part will come from either base repair, lateral resupply, or the depot.

LATSUPPLY. This subroutine occurs after LST has elapsed. The part is removed from file 96 and put into the base file. A check is made to see if a plane in the queue is waiting for that part, and if so, the part is put on the plane. A check is made to see if the plane has all its parts before entering back into the network to fly its next sortie.

DEPORDER. This subroutine occurs after OST has elapsed. The part is removed from the depot stock, if it is there, and placed in the base stock. The depot stock is decremented by one for that part, while the base receives one entity in its file, along with the part's attributes. Once the base stock has the part, a check of the NMCS queue is made to see if there are any planes waiting for that part. If a plane receives the part, a check is made to see if the

plane has all its parts, and if so, the plane enters back into the Network to fly the next sortie.

ADDPARTS. This subroutine is called from the network after a part is repaired at the depot. The stock quantity for the repaired part is incremented by one.

USERF. This user defined function assigns values to the attributes HRS, BASE, and GND. It is called from the Network after a plane lands at a new base after a sortie. The values are acquired from arrays defined in the INTLC subroutine.

INTLC. This subroutine is the first subroutine called by SLAM. In it, the data files for parts and sorties are opened, and the data is put into arrays for the sorties and attributes for the parts. Two other new files are also opened to receive data on individual part failures and totals for sorties and failures.

In addition, all the variables in the model are initialized to a starting value. This provides an easy means of changing the model parameters for different treatments or sensitivity analysis.

OTPUT. This subroutine is called by SLAM after a simulation run. It is used to transmit results to selected devices. Total sorties flown and part failures are sent to an external file to provide additional information on the activity in the scenario.

APPENDIX B: SLAM CODE

```
GEN,CAROLAN,THESIS NETWORK,09/01/86,1,N,N,Y,Y,Y,72;
   LIMITS,99,7,40000;
   PRIORITY/92,LVF(1);
   PRIORITY/96,LVF(8);
   ;
   ; FLIGHT TIMES BETWEEN BASE
   ;
   ARRAY(1,25)/0,2,1,4,5,5,17,5,13,17,23,24,23,23,23,
               23,23,23,24,23,23,23,32,38,29;
   ARRAY(2,25)/2,0,3,4,5,4,17,11,19,15,21,23,21,21,21,
               21,21,21,22,21,21,21,31,44,35;
   ARRAY(3,25)/1,3,0,4,4,6,17,5,13,18,24,25,24,24,24,
               24,24,24,25,24,24,24,32,38,29;
   ARRAY(4,25)/5,5,5,0,3,14,26,20,28,24,30,32,30,30,
               30,30,30,30,31,30,30,30,40,53,44;
   ARRAY(5,25)/6,6,5,3,0,14,26,20,28,24,30,32,30,30,
               30,30,30,30,31,30,30,30,40,53,44;
   ARRAY(6,25)/5,4,6,12,12,0,26,14,22,8,16,17,13,13,
               13,13,13,13,17,13,13,13,23,47,38;
   ARRAY(7,25)/15,21,15,29,29,29,0,8,4,13,10,4,19,19,
               19,19,19,19,4,19,19,19,16,41,32;
   ARRAY(8,25)/5,11,5,19,19,19,8,0,4,25,22,20,31,31,
               31,31,31,31,16,31,31,31,28,29,20;
   ARRAY(9,25)/13,18,13,27,27,26,4,4,0,21,18,16,27,27,
               27,27,27,27,12,27,27,27,24,33,24;
   ARRAY(10,25)/11,11,11,19,19,7,13,25,21,0,2,5,2,2,2,
                1,1,1,5,2,2,2,17,58,49;
   ARRAY(11,25)/18,18,18,26,26,13,10,22,18,3,0,2,2,2,
                2,2,2,2,2,2,2,2,14,51,42;
   ARRAY(12,25)/19,19,19,27,27,15,4,20,16,5,2,0,11,11,
                11,5,5,5,1,11,11,11,8,49,40;
   ARRAY(13,25)/17,17,17,25,25,13,19,31,27,2,2,11,0,1,
                1,2,2,2,11,1,1,1,20,64,55;
   ARRAY(14,25)/17,17,17,25,25,13,19,31,27,2,2,11,1,0,
                1,2,2,2,11,1,1,1,20,64,55;
   ARRAY(15,25)/17,17,17,25,25,13,19,31,27,2,2,11,1,1,
                0,2,2,2,11,1,1,1,20,64,55;
   ARRAY(16,25)/17,17,17,25,25,13,19,31,27,1,2,5,2,2,2,
                0,1,1,5,2,2,2,17,58,49;
   ARRAY(17,25)/17,17,17,25,25,13,19,31,27,1,2,5,2,2,2,
               1,0,1,5,2,2,2,17,58,49;
   ARRAY(18,25)/17,17,17,25,25,13,19,31,27,1,2,5,2,2,2,
                0,1,1,5,2,2,2,17,58,49;
   ARRAY(19,25)/19,19,19,27,27,15,4,16,12,5,2,1,11,11,
                11,5,5,5,0,11,11,11,8,49,40;
   ARRAY(20,25)/17,17,17,25,25,13,19,31,27,2,2,11,1,1,
                1,2,2,2,11,0,1,1,20,64,55;
   ARRAY(21,25)/17,17,17,25,25,13,19,31,27,2,2,11,1,1,
                1,2,2,2,11,1,0,1,20,64,55;
   ARRAY(22,25)/17,17,17,25,25,13,19,31,27,2,2,11,1,1,
                1,2,2,2,11,1,1,0,20,64,55;
   ARRAY(23,25)/27,27,27,35,35,27,16,28,24,17,1[illegible],8,20,
```

```
              20,20,17,17,17,8,20,20,20,0,57,48;
ARRAY(24,25)/38,38,38,46,46,44,26,29,33,58,51,49,64,
              64,64,58,58,58,49,64,64,64,57,0,4;
ARRAY(25,25)/29,29,29,37,37,35,17,20,24,49,42,40,55,
              55,55,49,49,49,40,55,55,55,48,4,0;
;
; BASE #   BASE NAME
; ------   ---------
;   1        KSUU
;   2        KTCM
;   3        KSBD
;   4        KWRI
;   5        KCHS
;   6        PAED
;   7        PGUA
;   8        PHNL
;   9        PWAK
;   10       RJTY
;   11       RODN
;   12       RPMK
;   13       RKTH
;   14       RKTY
;   15       RKSO
;   16       RJOI
;   17       RJTA
;   18       RJNK
;   19       RPMB
;   20       RKJK
;   21       RKJJ
;   22       RKTN
;   23       FJDJ
;   24       ASWM
;   25       ASRI
;
; **** FILES ****
;
; 1-25 :   BASE FILES OF PARTS
; 26-50 :  NMCS AIRCRAFT FILES (BASE = FILE# - 25)
; 51 :     DEPOT FILE OF ALL PARTS
; 52-89 :  AIRCRAFT FILES OF PARTS
; 91 : DUMP FILE
; 92 : TEMPORARY FILE USED IN LATERAL RESUPPLY
; 93 : PARTS WAITING FOR BASE LEVEL REPAIR
; 94 : PARTS AT DEPOT AWAITING REPAIR
; 95 : FAILED PARTS TO BE SHIPPED TO DEPOT FOR REPAIR
; 96 : PART WAITING FOR LATERAL SHIPMENT
; 97 : PARTS THAT FAILED AND NEEDING REPAIR
; 98 : PARTS TO BE ORDERED FROM DEPOT TO REPLENISH
;      BASE STOCK
;
; **** ENTITIES ****
;
; PLANES (38)
; PARTS (236 KINDS AT 25 BASES AND ON 37 PLANES)
```

```
;
; **** PLANE ATTRIBUTES ****
;
; ATRIB(2) : PLANE NUMBER
; ATRIB(3) : FLIGHT HOURS
; ATRIB(4) : PRESENT BASE LOCATION
; ATRIB(5) : ROW IN ARRAY CORRESPONDING TO PRESENT
;            SORTIE
; ATRIB(6) : QUEUE WAITING FOR PART
; ATRIB(7) : GROUND TIME (VARIES AT EACH BASE)
;
EQU/ATRIB(2),PNUM;
EQU/ATRIB(3),HRS;
EQU/ATRIB(4),BASE;
EQU/ATRIB(5),R;
EQU/ATRIB(6),QNUM;
EQU/ATRIB(7),GND;
;
; **** PART ATTRIBUTES ****
;
; ATRIB(1) : PART IDENTIFICATION
; ATRIB(2) : DEMAND (PROBABILITY OF FAILURE)
; ATRIB(3) : PROBABILITY OF LOCAL BASE BEING ABLE
;            TO REPAIR FAILED PART
; ATRIB(5) : REPAIR TIME FOR PART
; ATRIB(6) : QUANTITY AT THE DEPOT
; ATRIB(7) : QUANTITY IN THE WRSK
;
EQU/ATRIB(1),ID;
EQU/ATRIB(2),DEMAND;
EQU/ATRIB(3),PBFIX;
EQU/ATRIB(5),REPTM;
EQU/ATRIB(6),ND;
EQU/ATRIB(7),WRSK;
;
; **** GLOBAL VARIABLES ****
;
;EQU/XX(1),LAT;      SWITCH TO TURN LAT SUPPLY ON
;                    AND OFF (1=ON,0=OFF)
;EQU/XX(2),DSHIP;    SHIPMENT TIME TO DEPOT
;EQU/XX(3),AD;       ADMINISTRATIVE DELAY TIME FOR
;                    LATERAL RESUPPLY
EQU/XX(4),TAXI;      STANDARD TIME FOR START, TAXI,
;                    AND TAKEOFF
;EQU/XX(4),DEPOT;    COLUMN FOR DEPOT STOCK LEVEL
;EQU/XX(5),OST;      ORDER AND SHIP TIME
;EQU/XX(6),FAIL;     COUNTER FOR FAILED PARTS
;EQU/XX(7),SORTIE;   COUNTER FOR SORTIES FLOWN
;
; **** subroutines ****
;
; (1) PARTS:       DISTRIBUTE PARTS FROM THE DEPOT TO
;                  BASE STOCKS AND AIRCRAFT
; (2) CHECK:       CHECK IF ANY AIRCRAFT PARTS HAVE
```

```
;        FAILED
; (3) REPAIR:    CHECK IF THE FAILED PART CAN BE
;                REPAIRED
; (4) DRPAIRR:   REPAIR PART AT THE DEPOT
; (5) BREPAIR:   REPAIR PART AT THE LOCAL BASE
; (6) SEARCH:    CONDUCT SEARCH FOR REPLACEMENT PART
; (7) LATSUPPLY: SHIP PART FROM CLOSEST SOURCE
; (8) DEPORDER:  REPLENISH BASE STOCK FROM DEPOT
; (9) ADDPARTS:  INCREMENT BY ONE THE QUANTITY IN THE
;                DEPOT STOCK
;
NETWORK;
;
; **** PLANE CREATIONS AND ROUTING ****

       CREATE,0,25.5,1,1,1;          CREATE PLANE #1
       ASSIGN,PNUM = 52,
              R = 1;
       ACT,,,NEXT;

       CREATE,0,59.5,1,1,1;          CREATE PLANE #2
       ASSIGN,PNUM = 53,
              R = 7;
       ACT,,,NEXT;

       CREATE,0,42.25,1,1,1;         CREATE PLANE #3
       ASSIGN,PNUM = 54,
              R = 38;
       ACT,,,NEXT;

       CREATE,0,57,1,1,1;            CREATE PLANE #4
       ASSIGN,PNUM = 55,
              R = 65;
       ACT,,,NEXT;

       CREATE,0,71,1,1,1;            CREATE PLANE #5
       ASSIGN,PNUM = 56,
              R = 81;
       ACT,,,NEXT;

       CREATE,0,91,1,1,1;            CREATE PLANE #6
       ASSIGN,PNUM = 57,
              R = 87;
       ACT,,,NEXT;

       CREATE,0,88.75,1,1,1;         CREATE PLANE #7
       ASSIGN,PNUM = 58,
              R = 89;
       ACT,,,NEXT;

       CREATE,0,87.5,1,1,1;          CREATE PLANE #8
       ASSIGN,PNUM = 59,
              R = 106;
       ACT,,,NEXT;
```

```
        CREATE,0,20,1,1,1;              CREATE PLANE #9
        ASSIGN,PNUM = 60,
              R = 123;
PART    EVENT,1;                   CALLS SUBROUTINE PARTS
        ACT,,,NEXT;

        CREATE,0,65.5,1,1,1;            CREATE PLANE #10
        ASSIGN,PNUM = 61,
              R = 143;
        ACT,,,NEXT;

        CREATE,0,94,1,1,1;              CREATE PLANE #11
        ASSIGN,PNUM = 62,
              R = 159;
        ACT,,,NEXT;

        CREATE,0,83,1,1,1;              CREATE PLANE #12
        ASSIGN,PNUM = 63,
              R = 171;
        ACT,,,NEXT;

        CREATE,0,96.75,1,1,1;           CREATE PLANE #13
        ASSIGN,PNUM = 64,
              R = 194;
        ACT,,,NEXT;

        CREATE,0,96.25,1,1,1;           CREATE PLANE #14
        ASSIGN,PNUM = 65,
              R = 207;
        ACT,,,NEXT;

        CREATE,0,119,1,1,1;             CREATE PLANE #15
        ASSIGN,PNUM = 66,
              R = 214;
        ACT,,,NEXT;

        CREATE,0,102.75,1,1,1;          CREATE PLANE #16
        ASSIGN,PNUM = 67,
              R = 219;
        ACT,,,NEXT;

        CREATE,0,94.25,1,1,1;           CREATE PLANE #17
        ASSIGN,PNUM = 68,
              R = 236;
        ACT,,,NEXT;

        CREATE,0,110,1,1,1;             CREATE PLANE #18
        ASSIGN,PNUM = 69,
              R = 252;
        ACT,,,NEXT;

        CREATE,0,95.5,1,1,1;            CREATE PLANE #19
        ASSIGN,PNUM = 70,
```

```
       R = 268;
ACT,,,NEXT;

CREATE,0,80,1,1,1;              CREATE PLANE #20
ASSIGN,PNUM = 71,
       R = 281;
ACT,,,NEXT;

CREATE,0,123,1,1,1;             CREATE PLANE #21
ASSIGN,PNUM = 72,
       R = 288;
ACT,,,NEXT;

CREATE,0,145.5,1,1,1;           CREATE PLANE #22
ASSIGN,PNUM = 73,
       R = 307;
ACT,,,NEXT;

CREATE,0,197.5,1,1,1;           CREATE PLANE #23
ASSIGN,PNUM = 74,
       R = 324;
ACT,,,NEXT;

CREATE,0,103.75,1,1,1;          CREATE PLANE #24
ASSIGN,PNUM = 75,
       R = 336;
ACT,,,NEXT;

CREATE,0,130.25,1,1,1;          CREATE PLANE #25
ASSIGN,PNUM = 76,
       R = 342;
ACT,,,NEXT;

CREATE,0,146.25,1,1,1;          CREATE PLANE #26
ASSIGN,PNUM = 77,
       R = 353;
ACT,,,NEXT;

CREATE,0,149.25,1,1,1;          CREATE PLANE #27
ASSIGN,PNUM = 78,
       R = 374;
ACT,,,NEXT;

CREATE,0,174,1,1,1;             CREATE PLANE #28
ASSIGN,PNUM = 79,
       R = 385;
ACT,,,NEXT;

CREATE,0,147,1,1,1;             CREATE PLANE #29
ASSIGN,PNUM = 80,
       R = 394;
ACT,,,NEXT;

CREATE,0,138.5,1,1,1;           CREATE PLANE #30
```

```
          ASSIGN,PNUM = 81,
                 R = 406;
          ACT,,,NEXT;

          CREATE,0,173.5,1,1,1;           CREATE PLANE #31
          ASSIGN,PNUM = 82,
                 R = 415;
          ACT,,,NEXT;

          CREATE,0,174.25,1,1,1;          CREATE PLANE #32
          ASSIGN,PNUM = 83,
                 R = 422;
          ACT,,,NEXT;

          CREATE,0,162.5,1,1,1;           CREATE PLANE #33
          ASSIGN,PNUM = 84,
                 R = 437;
          ACT,,,NEXT;

          CREATE,0,191,1,1,1;             CREATE PLANE #34
          ASSIGN,PNUM = 85,
                 R = 454;
          ACT,,,NEXT;

          CREATE,0,257,1,1,1;             CREATE PLANE #35
          ASSIGN,PNUM = 86,
                 R = 465;
          ACT,,,NEXT;

          CREATE,0,273.25,1,1,1;          CREATE PLANE #36
          ASSIGN,PNUM = 87,
                 R = 474;
          ACT,,,NEXT;

          CREATE,0,349.25,1,1,1;          CREATE PLANE #37
          ASSIGN,PNUM = 88,
                 R = 490;
          ACT,,,NEXT;

          CREATE,0,487.25,1,1,1;          CREATE PLANE #38
          ASSIGN,PNUM = 89,
                 R = 507;
          ACT,,,NEXT;

          QUEUE(94);                  PARTS IN NEED OF REPAIR
            ACT(100),REPTM,,Q;        PART IS REPAIRED WITH
;                                     AMPLE SERVICE
Q         EVENT,9;                    PART GETS ADDED TO DEPOT
;                                     STOCK LEVEL
          TERM;

NEXT      ASSIGN,HRS = USERF(2);
          ACT,HRS;
          ASSIGN,BASE = USERF(1);
```

```
        ASSIGN,GND = USERF(3);
        ACT;

        EVENT,2;                        CALLS SUBROUTINE CHECK
        ACT,,,NOWAIT;                   CLONE GETS TERMINATED
        ENTER,2;
WAIT    ASSIGN,QNUM = BASE + 25;
        QUEUE(QNUM = 26,50);            PLANE WAITS IN REPAIR QUEUE.
NOWAIT  TERM;
FMC     ENTER,1;                        PLANE IS FMC
        GOON,1;
           ACT,,GND .EQ. 0,FIN;         LAST SORTIE, SO TERMINATE
           ACT,GND,GND .GT. 0;          SCHEDULED GROUND TIME
        ASSIGN,R = R + 1;
        ACT,TAXI,,NEXT;

FIN     TERM;
        ENDNET;
INIT,0,720;
FIN;

$
```

```
      PROGRAM MAIN
      DIMENSION NSET(1000000)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON QSET(1000000)
      EQUIVALENCE(NSET(1),QSET(1))
      NNSET=1000000
      NCRDR=5
      NPRNT=6
      NTAPE=7
      NPLOT=2
      CALL SLAM
      STOP
      END
C
C     ******************
C     *SUBROUTINE EVENT*
C     ******************

      SUBROUTINE EVENT(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      GO TO (1,2,3,4,5,6,7,8,9),I

1     CALL PARTS
      RETURN
2     CALL CHECK
      RETURN
3     CALL REPAIR
      RETURN
4     CALL DREPAIR
      RETURN
5     CALL BREPAIR
      RETURN
6     CALL SEARCH
      RETURN
7     CALL LATSUPPLY
      RETURN
8     CALL DEPORDER
      RETURN
9     CALL ADDPARTS
      RETURN
      END

C     ******************************************
C     * SUBROUTINE PARTS                       *
C     *                                        *
C     * THIS SUBROUTINE DISTRIBUTES THE AIRCRAFT *
C     * PARTS AMONG THE VARIOUS BASES, AND GIVES *
```

```
C      * EACH AIRCRAFT ONE PART OF EACH TYPE       *
C      ********************************************

1      SUBROUTINE PARTS
       COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
      1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
      1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
       COMMON/UCOM1/ PART(236,9), SORTI(520,5)

       REAL A(9)
C PLACE WRSK AT EACH C-141 BASE.  FOR MCCHORD,
C TRAVIS, AND NORTON, SUBTRACT THE AA SEGMENTS
C WHICH ARE GIVEN TO OSAN, POHANG, AND YECHON

       DO 30, K = 1,236

C M IS THE TOTAL WRSK QUANTITY
          M = PART(K,7)

C L IS THE AA WRSK SEGMENT OUANTITY
          L = PART(K,8)
          N = M-L

          IF (M .GT. 0) THEN
             CALL COPY(K,51,A)
             DO 20,J = 1,3
                DO 10,I = 1,N
                   CALL FILEM(J,A)
10              CONTINUE
20           CONTINUE
             DO 25,J = 4,5
                DO 15,I = 1,M
                   CALL FILEM(J,A)
15              CONTINUE
25           CONTINUE
          ENDIF
30     CONTINUE

C PLACE WRSK AA SEGMENT AT OSAN, POHANG, AND YECHON
       DO 31, K = 1,236
          M = PART(K,8)
          IF (M .GT. 0) THEN
             CALL COPY(K,51,A)
             DO 21,J = 13,15
                DO 11,I = 1,M
                   CALL FILEM(J,A)
11              CONTINUE
21           CONTINUE
          ENDIF
31     CONTINUE

C PLACE FSL STOCK AT ELMENDORF, ANDERSEN, AND HICKAM
       DO 32, K = 1,236
          M = PART(K,9)
```

```
          IF (M .GT. 0) THEN
             CALL COPY(K,51,A)
             DO 22,J = 6,8
                DO 12,I = 1,M
                   CALL FILEM(J,A)
12              CONTINUE
22           CONTINUE
          ENDIF
32     CONTINUE

C PLACE FSL STOCK AT YOKOTA, KADENA, AND CLARK
       DO 33, K = 1,236
          M = PART(K,9)
          IF (M .GT. 0) THEN
             CALL COPY(K,51,A)
             DO 23,J = 10,12
                DO 13,I = 1,M
                   CALL FILEM(J,A)
13              CONTINUE
23           CONTINUE
          ENDIF
33     CONTINUE

C CREATE FILE OF WRSK PARTS TO GO ON EACH AIRCRAFT
       DO 60,J=52,89
             DO 50,I=1,236
                 CALL COPY(I,51,A)
                 CALL FILEM(J,A)
50           CONTINUE
60     CONTINUE
       RETURN
       END

C      **********************************************
C      * SUBROUTINE CHECK                           *
C      *                                            *
C      * THIS SUBROUTINE CHECKS EACH AIRCRAFT PART  *
C      * TO DETERMINE IF THE PART HAS FAILED.       *
C      * FOR FAILED PARTS, A SEARCH PROCEDURE IS    *
C      * SCHEDULED TO LOCATE A REPLACEMENT PART,    *
C      * AND A REPAIR PROCEDURE IS SCHEDULED TO FIX *
C      * THE FAILED PART.  IF NO PARTS HAVE FAILED, *
C      * THE AIRCRAFT REENTERS THE NETWORK TO       *
C      * CONTINUE FLYING THE MISSION                *
C      **********************************************

2      SUBROUTINE CHECK
       COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
      1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
      1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

       REAL C(9),TEST(9)
       EQUIVALENCE(HRS,ATRIB(3))
       EQUIVALENCE(BASE,ATRIB(4))
```

```
      EQUIVALENCE(PNUM,ATRIB(2))
      L = BASE
      IFILE = PNUM
       XX(8) = XX(8) + 1
C CHECK IF ANY AIRCRAFT PARTS ARE BROKEN
      DO 20, I = 1,NNQ(IFILE)
         CALL RMOVE(1,IFILE,TEST)
         X = TEST(2) * -1
         Y = X*HRS
         PROBF = 1-EXP(Y)
         DRAW = DRAND(1)
         IF (DRAW .LE. PROBF) THEN
            XX(7) = XX(7) + 1
            IPART = TEST(1)
            WRITE(14,100)IPART,L
100         FORMAT(2X,I3,2X,I2)

C PLACE PART IN FILE FOR REPAIR
            CALL FILEM(97,TEST)

C SCHEDULE REPAIR
            CALL SCHDL(3,0,ATRIB)
         ELSE

C PUT PART BACK IN AIRPLANE FILE
            CALL FILEM(IFILE,TEST)
         ENDIF
20    CONTINUE

C IF PLANE HAS ALL ITS PARTS, ENTER PLANE BACK INTO
C THE NETWORK TO TAXI.
      NPLANE = NNQ(IFILE)
      IF (NNQ(IFILE) .EQ. NNQ(51)) THEN
         CALL ENTER(1,ATRIB)
      ENDIF
      RETURN
      END

C     ******************************************************
C     * SUBROUTINE REPAIR                                  *
C     *                                                    *
C     * THIS SUBROUTINE DETERMINES WHETHER A FAILED        *
C     * PART WILL BE REPAIRED AT THE LOCAL BASE            *
C     * REPAIR SHOP, OR AT THE DEPOT.  THE RESPECTIVE      *
C     * REPAIR PROCEDURES ARE THEN SCHEDULED.  IF SENT     *
C     * TO BASE REPAIR, THE TIME TO REPAIR IS THE BASE     *
C     * REPAIR TIME FOR THE INDIVIDUAL PART.  IF SENT      *
C     * TO THE DEPOT, A CONSTANT SHIPMENT TIME IS USED     *
C     ******************************************************

3     SUBROUTINE REPAIR
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
```

```
      REAL T(9)
      CALL RMOVE(1,97,T)
C BASE NUMBER MUST BE AN INTEGER
      L = ATRIB(4)

C CHECK ATRIB(3) OF THE FAILED PART TO SEE IF IT IS
C BASE REPAIRABLE
      BCHECK = DRAND(2)

C IF NOT BASE REPAIRABLE, SEND DIRECTLY TO DEPOT
      IF (BCHECK .GT. T(3)) GO TO 10

C CHECK TO SEE IF LOCAL BASE HAS REPAIR CAPABILITY
C IF FAILED PART IS AT A PSP OR FSL, REPAIR AND
C RESTOCKING CAN BE DONE THERE
      IF ((L .EQ. 1) .OR. (L.EQ.2) .OR. (L.EQ.3) .OR.
     $(L.EQ.4) .OR. (L.EQ.5) .OR. (L.EQ.6) .OR.
     $(L.EQ.7) .OR. (L.EQ.8) .OR. (L.EQ.10) .OR.
     $(L.EQ.11) .OR. (L.EQ.12)) THEN


C SIGNIFY THAT FAILED PART FOR THIS PLANE IS IN BASE
C REPAIR (ATRIB(8)=1)
            ATRIB(8) = 1

C PART CAN BE REPAIRED LOCALLY.  SCHEDULE BASE REPAIR
            CALL SCHDL(5,T(5),ATRIB)
C STORE PART IN REPAIR FILE FOR BASE REPAIR
            CALL FILEM(93,T)

      ELSE
C PART CANNOT BE REPAIRED LOCALLY.  SEND TO DEPOT
10          CALL SCHDL(4,XX(2),ATRIB)
C STORE PART IN REPAIR FILE FOR DEPOT SHIPMENT
           CALL FILEM(95,T)

C ORDER REPLACEMENT PART FROM DEPOT
            CALL SCHDL(8,XX(6),ATRIB)

C SIGNIFY THAT FAILED PART FOR THIS PLANE IS ORDERED
C FROM DEPOT
            ATRIB(8) = 0

C STORE PART IN FILE FOR DEPOT ORDER
            CALL FILEM(98,T)

      ENDIF

C STORE PART IN FILE FOR SEARCH
      CALL FILEM(90,T)

C START SEARCH FOR REPLACEMENT
      CALL SCHDL(6,0,ATRIB)
```

```
      RETURN
      END

C     **********************************************
C     * SUBROUTINE DEPOT REPAIR                    *
C     *                                            *
C     * THIS SUBROUTINE PLACES A FAILED PART IN THE*
C     * DEPOT FILE AFTER A DEPOT SHIPMENT TIME HAS *
C     * ELAPSED                                    *
C     **********************************************

4     SUBROUTINE DREPAIR
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      REAL U(9)
C     TAKE PART FROM DEPOT SHIP FILE AND PLACE IN
C     DEPOT REPAIR FILE
      CALL RMOVE(1,95,U)
      CALL FILEM(94,U)

      RETURN
      END

C     ************************
C     *SUBROUTINE BASE REPAIR*
C     ************************

5     SUBROUTINE BREPAIR
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      REAL V(9),Y(9)

      EQUIVALENCE(BASE,ATRIB(4))
      EQUIVALENCE(PNUM,ATRIB(2))

C REMOVE PART FROM REPAIR FILE AND PLACE IN BASE
C STOCK FILE
      M = PNUM
      L = BASE
      J = L + 25
      CALL RMOVE(1,93,V)
      CALL FILEM(L,V)

C REPAIRED PART IS NOW IN STOCK.  CHECK TO SEE IF
C THERE ARE ANY PLANES WAITING AT BASE QUEUE FOR PART
         NTRY = NFIND(1,J,2,0,PNUM,.1)
         IF (NTRY .GT. 0) THEN

C REMOVE PART JUST PLACED IN STOCK, AND PUT ON PLANE
```

```
              CALL RMOVE (NNQ(L),L,Y)
              CALL FILEM (M,Y)

C IF PLANE HAS ALL PARTS REMOVE PLANE FROM QUEUE AND
C ENTER INTO NETWORK TO TAXI
              IF (NNQ(M) .EQ. NNQ(51)) THEN
                 CALL RMOVE(NTRY,J,ATRIB)
                 CALL ENTER(1,ATRIB)
              ENDIF
           ENDIF

        RETURN
        END

C       ***************************************************
C       * SUBROUTINE SEARCH                               *
C       *                                                 *
C       * THIS SUBROUTINE LOOKS FOR A REPLACEMENT PART    *
C       * FOR THE ONE THAT FAILED.  FIRST, A CHECK OF     *
C       * BASE STOCK IS MADE.  IF THE PART IS FOUND IN    *
C       * STOCK, THE PLANE RECEIVES THE PART IN THE       *
C       * ALLOTTED GROUND TIME, AND A REPLACEMENT PART    *
C       * IS ORDERED FROM THE DEPOT.  IF BASE STOCK       *
C       * DOES NOT CONTAIN THE PART, THEN A CHECK IS      *
C       * MADE OF THE SURROUNDING BASES. ALL THE BASES    *
C       * HAVING THE PART IN STOCK ARE FIRST CONSIDERED,  *
C       * AND THEN THE CLOSEST OF THOSE BASES (IN TERMS   *
C       * OF FLYING TIME) IS USED TO PROVIDE THE RESUPPLY.*
C       ***************************************************
C
C       SUBROUTINE SEARCH
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
       1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
       1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

        REAL G(6), D(9), E(9), H(10), TEMP(9), OUT(9)
        INTEGER NSTOP

        EQUIVALENCE(BASE,ATRIB(4))
        EQUIVALENCE(PNUM,ATRIB(2))
        M = PNUM
        CALL RMOVE(1,90,D)

C CHECK BASE STOCK FIRST
        ZVAL = D(1)
        L = BASE
        NBASE = NFIND(1,L,1,0,ZVAL,.1)
        IF (NBASE .GT. 0) THEN
C REMOVE FROM BASE STOCK AND FIX PLANE
           CALL RMOVE(NBASE,L,E)
           CALL FILEM(M,E)

C IF PLANE HAS ALL ITS PARTS, IF IS FMC, AND ENTER
C BACK INTO NETWORK IF (NNQ(M) .EQ. NNQ(51)) THEN
```

```
              CALL ENTER(1,ATRIB)
           ENDIF

        ELSE
C PART IS NOT IN BASE STOCK
C IF LATERAL SUPPLY POLICY IS NOT IN EFFECT, SKIP
C NEXT SECTION
        IF (XX(1) .EQ. 0) GO TO 10

C CHECK TO SEE WHAT OTHER BASES HAVE THE PART IN STOCK
           NTO = BASE
           DO 60,I=1,25
              NLAT = NFIND(1,I,1,0,ZVAL,.1)
              IF (NLAT .GT. 0) THEN
                 NFROM = I
                 G(1) = GETARY(NFROM,NTO)
                 G(2) = I
                 G(3) = NFROM
                 G(4) = NTO

C FILE ACCORDING TO LVF ON ATRIB(1)
                 CALL FILEM(92,G)
              ENDIF

C OF THOSE BASES THAT HAVE THE PART, SELECT CLOSEST BASE
60         CONTINUE
           IF (NNQ(92) .GT. 0) THEN
              CALL RMOVE(1,92,TEMP)

C EMPTY ANY REMAINING ENTRIES IN FILE 13 FOR NEXT
C LATERAL RESUPPLY PROCESS
              IF (NNQ(92) .GT. 0) THEN
                 DO 80, J = 1,NNQ(92)
                    CALL RMOVE(1,92,OUT)
                    CALL FILEM(91,OUT)
80               CONTINUE
              ENDIF
              TSHIP = TEMP(1) + XX(3)
              I = TEMP(2)
              ILAT = NFIND(1,I,1,0,ZVAL,.1)
              CALL RMOVE(ILAT,I,H)
              H(8) = TNOW + TSHIP


C CHECK TO SEE IF FAILED PART IS IN BASE REPAIR SHOP
              IF (ATRIB(8) .EQ. 1) THEN

C CHECK TO SEE IF LATERAL SHIP TIME IS LESS THAN
C BASE REPAIR TIME
                 IF (TSHIP .LT. H(6)) THEN

C STORE IN FILE AWAITING LATERAL RESUPPLY (LVF ON
```

```
C H(8))
                    CALL FILEM(96,H)

C SCHEDULE LATERAL RESUPPLY TO OCCUR TSHIP TIME
C UNITS LATER
                    CALL SCHDL(7,TSHIP,ATRIB)
                 ENDIF
              ELSE
C PART HAS BEEN SENT TO DEPOT, AND A REPLACEMENT
C ORDERED FROM DEPOT.  IF LATERAL SHIP TIME IS LESS
C THAN DEPOT OST, ORDER THROUGH LAT SUPPLY.
                 IF (TSHIP .LT. XX(6)) THEN

C STORE IN FILE AWAITING LATERAL RESUPPLY
                    CALL FILEM(96,H)

C SCHEDULE LATERAL RESUPPLY TO OCCUR TSHIP TIME UNITS
C LATER
                    CALL SCHDL(7,TSHIP,ATRIB)
                 ENDIF
              ENDIF
           ENDIF

C PLACE PLANE IN QUEUE IF NOT ALREADY THERE
10      KQ = ATRIB(4) + 25
        NQ = NFIND(1,KQ,2,0,ATRIB(2),.1)
        IF (NQ .EQ. 0) THEN
           CALL ENTER(2,ATRIB)
        ENDIF
        ENDIF
70      RETURN
        END

C       ************************************************
C       * SUBROUTINE LATSUPPLY                         *
C       *                                              *
C       * THIS SUBROUTINE COMPLETES THE ACTION OF      *
C       * LATERAL RESUPPLY BY PLACING THE SUPPLIED     *
C       * PART IN THE BASE STOCK OF THE BASE REQUESTING*
C       * THE PART.  A CHECK IS MADE TO SEE IF ANY     *
C       * PLANES ARE WAITING IN THE BASE QUEUE FOR THAT*
C       * PART.                                        *
C       ************************************************

7       SUBROUTINE LATSUPPLY
        COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
       1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
       1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

        REAL P(9),S(9)

        EQUIVALENCE(PNUM,ATRIB(2))
        EQUIVALENCE(BASE,ATRIB(4))
        L = BASE
```

```
      J = L + 25
      M = PNUM
      CALL RMOVE(1,96,P)

C PLACE NEEDED PART INTO BASE FILE
      CALL FILEM(L,P)

C SEE IF THE PLANE THAT ORDERED THE PART IS STILL
C WAITING FOR THE PART
      NLOOK = NFIND(1,J,2,0,ATRIB(2),.1)
      IF (NLOOK .GT. 0) THEN

C REMOVE THE PART JUST PLACED IN BASE STOCK
         CALL RMOVE(NNQ(L),L,S)

C GIVE THE PART TO THE PLANE IN NEED
         CALL FILEM(M,S)
         IF (NNQ(M) .EQ. NNQ(51)) THEN

C PLANE IS NOW FMC.  ENTER BACK INTO NETWORK TO TAXI
            CALL RMOVE(NLOOK,J,ATRIB)
            CALL ENTER(1,ATRIB)
         ENDIF
      ENDIF
      RETURN
      END

C     ***********************************************
C     * SUBROUTINE DEPORDER                         *
C     *                                             *
C     * THIS SUBROUTINE COMPLETES THE ACTION OF     *
C     * ORDERING A PART FROM THE DEPOT AFTER A PART *
C     * IS SENT TO THE DEPOT.  A CHECK IS MADE OF   *
C     * THE BASE NMC QUEUE TO SEE IF THERE ARE ANY  *
C     * PLANES WAITING FOR THE PART.                *
C     ***********************************************

8     SUBROUTINE DEPORDER
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      DIMENSION NSET(500000)
      COMMON QSET(500000)
      EQUIVALENCE(NSET(1),QSET(1))

      REAL R(9),Q(9),S(9),T(9)
      CALL RMOVE(1,98,Q)
      J = ATRIB(4)
      L = J + 25
C REMOVE PART FROM DEPOT FILE, IF IT'S THERE, AND
C GIVE TO BASE FILE
      NTRY = NFIND(1,51,1,0,Q(1),.1)
      CALL COPY(NTRY,51,R)
```

```
      IF (R(XX(5)) .GT. 0) THEN

C PUT PART IN BASE STOCK
         CALL FILEM(J,R)

C DECREMENT DEPOT STOCK BY ONE
         NTRY = LOCAT(NTRY,51)
         QSET(NTRY + XX(5)) = QSET(NTRY + XX(5)) - 1

C SEE IF THERE ARE ANY PLANES WAITING FOR THE PART
C AT THIS BASE
         IF (NNQ(L) .GT. 0) THEN
            DO 10,K=1,NNQ(L)
               IF (NSTOP .EQ. 0) THEN
                  CALL RMOVE(1,L,S)
                  M = S(2)

C FIND THE FIRST ENTRY IN PLANE FILE WITH PART ID THE
C SAME AS PART GAINED
                  NTRY = NFIND(1,M,1,0,Q(1),.1)
                  IF (NTRY .EQ. 0) THEN

C PART IS MISSING AND PLANE CAN USE PART
                     CALL RMOVE(NNQ(J),J,T)
                     CALL FILEM(M,T)
                     NSTOP = 1
                     IF (NNQ(M) .EQ. NNQ(51)) THEN

C PLANE IS NOW FMC.  ENTER BACK INTO NETWORK TO TAXI
                        CALL ENTER(1,S)
                     ENDIF
                  ELSE

C PUT THE PLANE BACK IN THE QUEUE
                     CALL FILEM(L,S)
                  ENDIF
               ENDIF
10          CONTINUE
         NSTOP = 0
         ENDIF
      ELSE
         PRINT *,'OUT OF STOCK FOR PART',R(1)
      ENDIF
      RETURN
      END

C     ************************************************
C     * SUBROUTINE ADDPARTS                          *
C     *                                              *
C     * THIS SUBROUTINE UPDATES THE STOCK LEVEL AT    *
C     * THE DEPOT BY INCREMENTING THE THE QUANTITIES *
C     * OF THE RESPECTIVE PARTS AFTER THEY ARE       *
C     * REPAIRED AT THE DEPOT                        *
C     ***************+********************************
```

```
9     SUBROUTINE ADDPARTS
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      DIMENSION NSET(500000)
      COMMON QSET(500000)
      EQUIVALENCE(NSET(1),QSET(1))

C INCREMENT QUANTITY OF DEPOT STOCK FOR REPAIRED PART
      NTRY = NFIND(1,51,1,0,ATRIB(1),.1)
      NTRY = LOCAT(NTRY,51)
      QSET(NTRY + XX(5)) = QSET(NTRY + XX(5)) + 1

      RETURN
      END

C     ******************************************************
C     * USERF FUNCTION                                     *
C     *                                                    *
C     * THIS FUCTION YIELDS THE VALUES FOR THE             *
C     * ATTRIBUTES BASE, FLIGHT TIME AND GROUND TIME,*
C     * WHICH ARE STORED IN A DATA FILE.                  *
C     ******************************************************

      FUNCTION USERF(I)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/PART(236,9), SORTI(520,5)

C ROW NUMBER MUST BE AN INTEGER
      NR = ATRIB(5)

      GO TO (1,2,3),I

1     USERF = SORTI(NR,3)
      RETURN
2     USERF = SORTI(NR,4)
      RETURN
3     USERF = SORTI(NR,5)
      RETURN
      END

C     ******************
C     *SUBROUTINE INTLC*
C     ******************

      SUBROUTINE INTLC
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)
      COMMON/UCOM1/PART(236,9), SORTI(520,5)
```

```
      EQUIVALENCE(TAXI,XX(4))

      INTEGER REPTM
      REAL A(7)
C READ IN FILE OF SORTI DATA
      OPEN(12,FILE='[WCAROLAN]SORTIE.DAT',STATUS='OLD')
      OPEN(13,FILE='[WCAROLAN]SPARES2.DAT',STATUS='OLD')
      OPEN(14,FILE='[WCAROLAN]FAILURES.DAT',STATUS='NEW')
      OPEN(15,FILE='[WCAROLAN]RESULTS.DAT',STATUS='NEW')
      DO 10, I = 1,520
         READ(12,200)N,M,J,F,G
         SORTI(I,1) = N
         SORTI(I,3) = J
         SORTI(I,4) = F
         SORTI(I,5) = G
10    CONTINUE

C READ IN FILE OF SPARES DATA

      DO 30, I = 1,236
         READ (13,300)ID,DEMAND,PBFIX,PDFIX,REPTM,ND
     1        ,NWRSK,NAA,NFSL
         A(1) = ID
         A(2) = DEMAND
         A(3) = PBFIX
         A(4) = PDFIX
         A(5) = REPTM
         A(6) = ND
         A(7) = NWRSK
         CALL FILEM(51,A)
         PART(I,7) = NWRSK
         PART(I,8) = NAA
         PART(I,9) = NFSL
30    CONTINUE
      CLOSE(12)
      CLOSE(13)

C LATERAL SUPPLY POLICY (ON = 1, OFF = 0)
      XX(1) = 1.

C SHIP TIME TO THE DEPOT (HOURS)
      XX(2) = 48.
C ADMINISTRATIVE DELAY TIME FOR LATERAL SHIPMENT (HRS)
      XX(3) = 24.

C COUNTERS
      XX(7) = 0.

      XX(8) = 0.


C DEPOT STOCK LEVEL (6 = UNLIMITED, 7 = LIMITED)
      XX(5) = 7.
```

```
C ORDER & SHIP TIME FROM THE DEPOT
      XX(6) = 168.
      TAXI = 0.25
      RETURN
      END

      SUBROUTINE OTPUT
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW
     1,II,MFA,MSTOP,NCLNR,NCRDR,NPRNT,NNRUN,NNSET
     1,NTAPE,SS(100),SSL(100),TNEXT,TNOW,XX(100)

      PRINT *,'NUMBER OF SORTIES FLOWN = ',XX(8)
      PRINT *,'NUMBER OF FAILED PARTS = ',XX(7)
      DO 40, I = 26,50
         TOT = FFAVG(I) + TOT
40    CONTINUE
      PRINT *,'NMCS',TOT
      WRITE(15,500)XX(8),XX(7),TOT
500   FORMAT('SORTIES FLOWN',I3,'PARTS FAILED',I3,
     1       'NMCS',F6.2F)
      RETURN
      END

$
```

APPENDIX C: SORTIE DATA

COLUMN 1: SORTIE NUMBER
COLUMN 2: PLANE NUMBER
COLUMN 3: BASE NUMBER
COLUMN 4: SORTIE LENGTH
COLUMN 5: GROUND TIME

1	52	6	5.25	15.75
2	52	10	8.5	16.5
3	52	20	2.0	3.25
4	52	7	5.5	2.25
5	52	8	7.25	44.25
6	52	1	5.5	0
7	53	6	4.25	3.25
8	53	11	10.0	18.45
9	53	12	2.5	2.25
10	53	11	2.5	16.0
11	53	13	2.	1.5
12	53	11	2.	2.25
13	53	13	2.	1.5
14	53	11	2.	10.75
15	53	13	2.	1.5
16	53	10	2.	2.25
17	53	13	2.	1.5
18	53	11	2.25	10.5
19	53	13	2.	1.5
20	53	11	2.	2.25
21	53	13	2.	1.5
22	53	11	2.	10.75
23	53	13	2.	1.5
24	53	10	2.0	2.25
25	53	13	2.	1.5
26	53	11	2.	10.75
27	53	13	2.	1.5
28	53	11	2.	2.25
29	53	13	2.	1.5
30	53	11	2.	10.75
31	53	13	2.	1.5
32	53	11	2.	2.25
33	53	13	2.	1.5
34	53	11	2.	37.75
35	53	10	2.5	3.25
36	53	8	7.25	3.25
37	53	2	6.	0.
38	54	6	6.	3.25
39	54	10	8.5	34.0
40	54	13	2.	2.25
41	54	12	4.	3.25
42	54	23	8.5	17.0

43	54	12	8.	3.25
44	54	11	2.75	8.5
45	54	12	2.5	2.25
46	54	11	2.5	4.25
47	54	14	2.	2.25
48	54	19	4.	2.25
49	54	12	0.5	17.5
50	54	14	4.	2.25
51	54	16	1.	2.25
52	54	11	1.5	15.0
53	54	14	2.	2.25
54	54	16	1.	2.25
55	54	11	1.5	8.0
56	54	10	2.5	2.25
57	54	12	5.	2.25
58	54	11	2.5	13.0
59	54	18	2.75	2.25
60	54	10	0.75	16.75
61	54	15	2.	4.0
62	54	10	2.	2.25
63	54	8	7.5	3.25
64	54	3	6.75	0.
65	55	6	6.	3.25
66	55	10	8.5	34.0
67	55	13	2.	2.25
68	55	12	4.	3.25
69	55	23	8.5	17.0
70	55	12	8.	3.25
71	55	11	2.75	24.0
72	55	15	2.	2.25
73	55	12	4.	3.25
74	55	24	8.25	22.0
75	55	25	0.75	2.25
76	55	12	8.5	15.25
77	55	15	4.	2.25
78	55	10	2.	2.25
79	55	8	7.5	3.25
80	55	2	6.	0.
81	56	6	6.75	3.25
82	56	11	10.0	5.0
83	56	20	2.	3.25
84	56	10	2.	2.25
85	56	8	7.5	3.25
86	56	3	11.5	0.
87	57	8	9.	40.0
88	57	3	5.5	0.
89	58	2	6.	17.0
90	58	8	6.	3.25
91	58	10	10.5	15.25
92	58	14	2.	2.25
93	58	16	1.	2.25
94	58	14	1.	2.25
95	58	16	1.	2.25
96	58	15	1.25	2.25

97	58	11	2.	6.25
98	58	14	2.	2.25
99	58	16	1.	2.25
100	58	22	1.	2.25
101	58	11	2.	14.25
102	58	15	2.	2.25
103	58	10	2.	2.25
104	58	8	7.5	3.5
105	58	5	11.5	0.
106	59	6	4.25	3.25
107	59	10	8.25	2.25
108	59	11	2.5	8.5
109	59	14	2.	2.25
110	59	19	4.0	2.25
111	59	11	3.	10.75
112	59	15	2.	2.25
113	59	11	2.	4.25
114	59	12	2.5	2.25
115	59	15	4.	2.25
116	59	11	2.	31.25
117	59	22	2.	2.25
118	59	10	2.	16.25
119	59	15	2.	2.25
120	59	10	2.	2.25
121	59	8	7.5	3.25
122	59	2	6.	0.
123	60	6	6.	16.5
124	60	10	8.5	21.0
125	60	14	2.	2.25
126	60	19	4.	2.25
127	60	11	2.5	33.0
128	60	15	2.	2.25
129	60	12	4.	17.75
130	60	14	4.	1.5
131	60	19	4.	2.25
132	60	12	0.75	12.0
133	60	14	4.	1.5
134	60	19	4.	2.25
135	60	12	0.75	11.0
136	60	13	4.	1.5
137	60	11	2.	13.75
138	60	21	2.	2.25
139	60	10	2.	2.25
140	60	8	7.25	3.25
141	60	1	5.5	2.25
142	60	3	10.5	0.
143	61	6	8.5	17.0
144	61	10	9.	18.0
145	61	21	2.	2.25
146	61	11	2.	2.25
147	61	21	2.	2.25
148	61	11	2.	11.25
149	61	22	2.	2.25
150	61	7	5.	17.75

151	61	15	5.	3.25
152	61	12	5.	26.75
153	61	20	4.	2.25
154	61	12	4.	14.75
155	61	20	4.	2.25
156	61	10	2.	2.25
157	61	8	7.25	3.25
158	61	5	11.	0.
159	62	14	2.	2.25
160	62	19	4.	2.25
161	62	11	5.	8.5
162	62	14	2.	2.25
163	62	19	4.	2.25
164	62	11	2.5	7.5
165	62	15	2.	2.25
166	62	10	2.	2.25
167	62	8	7.5	3.25
168	62	2	6.	2.25
169	62	1	1.75	2.25
170	62	3	1.25	0.
171	63	6	8.25	3.25
172	63	10	8.5	16.0
173	63	14	2.	2.25
174	63	19	4.	2.25
175	63	11	3.	10.5
176	63	14	2.	2.25
177	63	19	4.	2.25
178	63	12	0.75	15.25
179	63	11	4.	15.25
180	63	14	2.	2.25
181	63	19	4.	2.25
182	63	12	0.75	13.75
183	63	14	4.	2.25
184	63	16	1.	2.25
185	63	11	1.5	15.0
186	63	14	2.	2.25
187	63	16	1.	2.25
188	63	11	1.5	9.25
189	63	15	2.25	2.25
190	63	10	2.	2.25
191	63	8	7.5	3.25
192	63	1	5.	2.25
193	63	4	5.5	0.
194	64	8	6.	8.75
195	64	10	10.5	2.25
196	64	21	2.	2.25
197	64	11	2.	13.5
198	64	13	2.	1.5
199	64	11	2.	26.0
200	64	15	2.	2.25
201	64	12	4.	10.0
202	64	21	4.	2.25
203	64	10	2.	2.25
204	64	8	7.25	3.25

205	64	1	5.5	2.25
206	64	3	9.5	0.
207	65	1	4.75	2.
208	65	8	6.5	2.75
209	65	10	10.5	20.25
210	65	14	2.	2.25
211	65	18	1.	2.25
212	65	17	0.75	2.0
213	65	10	1.	0.
214	66	15	2.	3.25
215	66	10	2.	2.25
216	66	8	7.5	3.25
217	66	1	6.5	2.25
218	66	3	9.5	0.
219	67	1	6.	2.25
220	67	4	5.5	2.25
221	67	10	10.5	2.25
222	67	14	2.	2.25
223	67	19	4.	2.25
224	67	11	2.5	5.5
225	67	14	2.	2.25
226	67	19	4.	2.25
227	67	11	2.5	11.0
228	67	14	2.	2.25
229	67	19	4.	2.25
230	67	11	2.5	6.0
231	67	22	2.	3.25
232	67	10	2.	3.25
233	67	8	7.25	5.5
234	67	1	5.25	3.25
235	67	4	6.	0.
236	68	8	6.	15.25
237	68	11	11.25	2.25
238	68	14	2.	2.25
239	68	11	2.	2.25
240	68	15	2.	2.25
241	68	12	4.	2.25
242	68	15	4.	2.25
243	68	11	2.	28.25
244	68	15	2.	2.25
245	68	11	2.	2.25
246	68	15	2.	3.25
247	68	11	2.25	2.25
248	68	8	8.5	3.25
249	68	2	6.	2.25
250	68	1	2.	16.25
251	68	3	1.	0.
252	69	8	6.	3.25
253	69	11	11.5	2.25
254	69	15	2.	2.25
255	69	11	2.	6.0
256	69	14	2.	2.25
257	69	16	1.	2.25
258	69	15	1.	2.25

259	69	11	2.	10.0
260	69	22	2.	2.25
261	69	19	4.	2.25
262	69	12	0.75	11.0
263	69	15	4.	2.25
264	69	10	2.	2.25
265	69	8	7.5	3.25
266	69	1	5.5	2.25
267	69	3	2.5	0.
268	70	8	5.75	16.25
269	70	10	11.	2.25
270	70	22	2.	3.0
271	70	11	2.	13.25
272	70	14	2.25	2.25
273	70	19	4.	2.25
274	70	11	2.25	11.0
275	70	14	2.	2.25
276	70	19	4.	2.25
277	70	11	2.25	27.0
278	70	10	2.25	3.25
279	70	8	7.5	3.25
280	70	2	9.25	0.
281	71	6	8.	19.0
282	71	11	10.	19.75
283	71	22	2.	3.25
284	71	7	6.	2.25
285	71	8	7.5	25.75
286	71	1	5.	2.25
287	71	4	7.25	0.
288	72	1	6.	2.25
289	72	8	5.5	2.25
290	72	10	10.5	2.25
291	72	15	2.	2.25
292	72	12	4.	2.25
293	72	15	4.	2.25
294	72	12	4.	2.25
295	72	15	4.	2.25
296	72	12	4.	15.25
297	72	15	4.	2.25
298	72	12	4.	24.5
299	72	21	4.	2.25
300	72	10	2.	47.75
301	72	15	2.	2.25
302	72	21	1.	2.25
303	72	10	2.	2.25
304	72	8	7.	3.75
305	72	1	5.	18.0
306	72	4	6.5	0.
307	73	13	4.	2.25
308	73	11	2.	12.25
309	73	22	2.	2.25
310	73	19	4.	2.25
311	73	11	2.5	16.25
312	73	12	2.5	2.25

313	73	11	2.	17.0
314	73	15	2.	2.25
315	73	11	2.	12.75
316	73	14	2.	2.25
317	73	16	1.	2.25
318	73	10	0.75	43.0
319	73	18	0.75	1.75
320	73	15	2.	2.25
321	73	10	2.	2.25
322	73	8	7.5	3.25
323	73	1	5.	0.
324	74	10	2.5	2.25
325	74	11	2.25	12.25
326	74	13	2.	1.5
327	74	11	2.	18.5
328	74	13	2.	1.5
329	74	11	2.	22.25
330	74	18	3.	2.25
331	74	10	1.	11.0
332	74	15	2.	2.25
333	74	10	2.	19.75
334	74	2	9.5	2.25
335	74	1	1.5	0.
336	75	8	10.45	15.25
337	75	11	10.5	21.75
338	75	22	2.	3.0
339	75	9	6.5	16.5
340	75	8	5.5	37.0
341	75	5	11.75	0.
342	76	8	6.	3.25
343	76	10	8.5	17.5
344	76	15	2.	2.25
345	76	10	2.	19.75
346	76	8	7.5	16.0
347	76	10	9.5	13.5
348	76	15	2.	2.25
349	76	10	2.	2.25
350	76	8	7.5	3.25
351	76	3	5.5	2.25
352	76	3	9.	0.
353	77	8	6.	2.25
354	77	10	11.5	3.25
355	77	13	2.	1.5
356	77	11	2.	2.25
357	77	13	2.	1.5
358	77	11	2.	16.0
359	77	10	2.5	2.25
360	77	11	2.5	10.25
361	77	13	2.	1.5
362	77	11	2.	2.25
363	77	13	2.	1.5
364	77	11	2.	10.75
365	77	13	2.	1.5
366	77	11	2.	2.25

367	77	13	2.	1.5
368	77	11	2.	33.75
369	77	15	2.	2.25
370	77	10	2.	2.25
371	77	8	7.5	3.25
372	77	1	5.	2.25
373	77	3	1.5	0.
374	78	8	6.	2.25
375	78	10	10.5	2.25
376	78	22	2.	2.25
377	78	12	4.5	16.0
378	78	22	4.	2.25
379	78	12	4.	35.75
380	78	15	4.	2.25
381	78	10	2.	2.25
382	78	8	7.5	3.25
383	78	2	6.	2.25
384	78	3	2.75	0.
385	79	14	1.	2.25
386	79	16	1.	16.75
387	79	14	1.	2.25
388	79	16	1.	17.25
389	79	22	1.	2.25
390	79	10	2.	2.25
391	79	8	7.5	3.25
392	79	1	5.	2.25
393	79	5	6.5	0.
394	80	8	6.25	2.25
395	80	10	11.5	3.25
396	80	13	2.	2.25
397	80	11	2.	20.0
398	80	21	2.	2.25
399	80	12	4.	32.75
400	80	15	4.	2.25
401	80	12	4.	18.75
402	80	15	4.	2.25
403	80	10	2.	2.25
404	80	8	7.5	3.25
405	80	2	6.	0.
406	81	1	4.	15.25
407	81	8	5.5	2.25
408	81	7	8.5	1.5
409	81	11	3.5	14.0
410	81	22	2.	2.25
411	81	10	2.	2.25
412	81	8	7.5	3.25
413	81	1	5.5	2.25
414	81	4	7.25	0.
415	82	8	6.	2.25
416	82	10	10.5	2.25
417	82	22	2.	2.25
418	82	10	2.	2.25
419	82	8	7.5	3.25
420	82	1	5.5	2.25

421	82	1	10.5	0.
422	83	8	6.	3.25
423	83	10	10.5	18.0
424	83	22	2.	2.25
425	83	10	2.	41.75
426	83	11	2.5	2.25
427	83	18	3.	2.25
428	83	10	1.	25.0
429	83	15	2.	2.25
430	83	12	4.	3.25
431	83	25	8.5	21.0
432	83	12	8.25	16.25
433	83	15	4.	2.25
434	83	10	2.	18.75
435	83	2	9.5	23.0
436	83	3	2.5	0.
437	84	1	6.	2.25
438	84	8	5.5	15.75
439	84	10	10.5	20.5
440	84	14	2.	2.25
441	84	16	1.	19.75
442	84	14	1.	2.25
443	84	16	1.	36.75
444	84	14	1.	2.25
445	84	16	1.	19.75
446	84	14	1.	2.25
447	84	16	1.	2.25
448	84	21	1.	2.25
449	84	12	4.	6.0
450	84	16	3.	2.25
451	84	8	8.5	3.25
452	84	2	6.	2.25
453	84	5	5.	0.
454	85	8	16.	16.5
455	85	10	10.5	18.0
456	85	13	2.	2.25
457	85	10	2.	2.25
458	85	8	7.5	18.0
459	85	10	10.5	1.75
460	85	15	4.	2.25
461	85	10	2.	2.25
462	85	8	7.5	4.25
463	85	1	5.5	2.25
464	85	3	6.	0.
465	86	8	6.	17.75
466	86	24	11.5	4.5
467	86	25	0.75	20.0
468	86	12	8.25	2.25
469	86	11	2.5	30.5
470	86	10	2.5	2.25
471	86	8	7.5	3.25
472	86	3	6.	2.25
473	86	1	1.25	0.
474	87	1	4.	4.25

475	87	8	5.5	19.25
476	87	10	10.5	2.25
477	87	16	1.	20.0
478	87	11	1.	18.0
479	87	13	2.	1.5
480	87	11	2.	2.25
481	87	13	2.	1.5
482	87	11	2.	35.75
483	87	13	2.	2.25
484	87	11	2.	16.75
485	87	15	2.	2.25
486	87	10	2.	2.25
487	87	8	7.5	3.25
488	87	1	5.5	2.25
489	87	4	6.	0.
490	88	8	6.	3.25
491	88	10	10.5	17.0
492	88	21	2.	2.25
493	88	12	4.	2.25
494	88	11	2.5	54.5
495	88	18	2.5	2.25
496	88	11	3.	16.25
497	88	18	2.5	2.25
498	88	11	2.75	42 0
499	88	15	2.	2.25
500	88	10	2.	2.25
501	88	8	7.5	23.0
502	88	10	10.5	23.0
503	88	15	2.	2.25
504	88	10	2.	2.25
505	88	8	7.5	3.25
506	88	5	11.0	0.
507	89	8	6.	3.25
508	89	10	10.5	20.5
509	89	13	2.	2.25
510	89	11	2.	16.25
511	89	13	2.	1.5
512	89	11	2.	2.25
513	89	13	2.	1.5
514	89	11	2.	34.75
515	89	21	2.	2.25
516	89	11	2.	16.75
517	89	15	2.	2.25
518	89	10	2.	10.75
519	89	1	10.	30.0
520	89	2	10.	0.

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APPENDIX D: PARTS DATA

COL 1: PART NUMBER USED IN MODEL
COL 2: DEMAND RATE FOR PART (PER HOUR)
COL 3: PROBABILITY OF BASE REPAIR
COL 4: PROBABILITY OF DEPOT REPAIR
COL 5: REPAIR TIME (HOURS)
COL 6: QUANTITY OF EACH PART IN DEPOT STOCK
COL 7: QUANTITY OF EACH PART IN WRSK
COL 8: QUANTITY OF EACH PART IN AA SEGMENT
COL 9: QUANTITY OF EACH PART IN TB SEGMENT
COL 10: NATIONAL STOCK NUMBER (NSN)
COL 11: NOUN

1	0.000162	0.89	1.00	72	100	2			1045006408487	ACCUMULATOR
2	0.001605	0.80	1.00	240	100	2			1560000744238	RADOME NOSE
3	0.00005	0.80	1.00	120	100	1			1560000758927	DOORTHRUST
4	0.000974	0.40	1.00	72	100	1			1560007531751	BELLCRANKL
5	0.001023	0.36	1.00	72	100	1			1560007579056	BELLCRANK
6	0.000533	0.80	1.00	144	100	1			1560007941567	NOSEDOME
7	0.000193	0.20	1.00	192	100	1			1560008716282	CARTRIDGE
8	0.000182	0.10	1.00	120	100	1			1560009184010	CYLINDER
9	0.000115	0.24	1.00	96	100	1			1560009393719	CARTRIDGE
10	0.000052	0.52	1.00	168	100	8	0	2	1560010455724	RAMP
11	0.000367	0.97	1.00	144	100	3			1620009825059	POSITIONER
12	0.003220	0.87	1.00	192	100	36	4	6	1630000816687	WHEEL NLG
13	0.000071	0.77	1.00	240	100	4	0	1	1630002038811	DETECTOR
14	0.000052	0.06	1.00	24	100	1			1630007583758	VALVE
15	0.001347	0.95	1.00	96	100	8	0	2	1630008810815	BRAKE ASSY
16	0.002869	0.48	1.00	120	100	10	1	1	1630010851864	CONTROL BX
17	0.001642	0.70	1.00	144	100	60	4	10	1630011326400	WHEEL LAND
18	0.000112	0.62	1.00	192	100	2			1650000158830	VALVE
19	0.000150	0.55	1.00	192	100	1			1650002089693	VALVE
20	0.001670	0.10	1.00	48	100	1			1650007282780	MOTOR
21	0.000017	0.71	1.00	96	100	1			1650007573863	CYL HYD
22	0.000141	0.09	1.00	168	100	2			1650007667961	MOTOR
23	0.000153	0.08	1.00	120	100	2			1650008252590	MOTOR ASSY
24	0.000352	0.06	1.00	96	100	1			1650008326780	VALVE
25	0.000206	0.09	1.00	120	100	2			1650008369769	WIRE HARN
26	0.000026	0.81	1.00	168	100	1			1650008668218	VALVE LINE
27	0.000302	0.18	1.00	96	100	2			1650008720320	VALVE
28	0.000414	0.90	1.00	168	100	2			1650009060040	CYL CARGO
29	0.000036	0.86	1.00	192	100	1			1650009139886	CYLINDER
30	0.000690	0.24	1.00	216	100	6	0	1	1650009303160	DRIVE ASSY
31	0.000213	0.15	1.00	192	100	1			1650009304714	GEARBOX
32	0.000019	0.74	1.00	168	100	1			1650009332936	VALVE SLTR
33	0.000324	0.07	1.00	120	100	3			1650009360696	CONTROL
34	0.000056	0.61	1.00	120	100	1			1650009360704	VALVE
35	0.000113	0.09	1.00	192	100	1			1650009374099	MOTOR
36	0.000046	0.48	1.00	216	100	1			1650009393578	SWITCH BOX
37	0.000036	0.58	1.00	192	100	1			1650009393579	SWITCH BOX
38	0.000028	0.36	1.00	264	100	1			1650009438822	OIL TANK

39	0.000330	0.11	1.00	72	100	3			1650009446740	ACTUATOR
40	0.000382	0.10	1.00	120	100	2			1650009446741	ACTUATOR
41	0.000055	0.67	1.00	144	100	2			1650009959312	CYL RAMP
42	0.000175	0.10	1.00	216	100	1			1650009995350	ACTUATOR
43	0.000314	0.09	1.00	120	100	2			1650010771215	CNTRL ASSY
44	0.000226	0.11	1.00	360	100	3			1650011353164	CONTROL
45	0.000472	0.25	1.00	96	100	3			1660000215439	CONTROL BOX
46	0.000276	0.28	1.00	96	100	2			1660000215440	CONTROL
47	0.000103	0.08	1.00	120	100	1			1660000707374	VALVE
48	0.000157	0.22	1.00	120	100	2			1660000716390	CONTROL
49	0.000177	0.06	1.00	168	100	6	0	1	1660001952729	02 REGLTR
50	0.000308	0.13	1.00	168	100	3			1660005712238	CONVERTER
51	0.000481	0.07	1.00	216	100	3			1660005731742	CONTROLLER
52	0.000094	0.33	1.00	72	100	1			1660005736481	VALVE
53	0.000106	0.04	1.00	72	100	1			1660005736482	VALVE
54	0.000073	0.84	1.00	240	100	2			1660006888451	CONTROL BOX
55	0.000096	0.89	1.00	144	100	4	0	1	1660007524980	CONTROL BOX
56	0.000149	0.16	1.00	120	100	2			1660007961682	VALVE
57	0.000280	0.12	1.00	288	100	2			1660008998380	CONVERTER
58	0.000322	0.21	1.00	168	100	4	0	1	1660009123650	CONTROL
59	0.000753	0.97	1.00	144	100	4	0	1	1680001183304	WHEEL CONT
60	0.000308	0.12	1.00	168	100	3			1680002533843	BRAKE ASSY
61	0.000208	0.31	1.00	192	100	10	1	1	1680006889991	ACTUATOR
62	0.000485	0.31	1.00	72	100	4	0	1	1680008670344	ACTUATOR
63	0.000177	0.18	1.00	168	100	4	0	1	1680008699545	COMPARATOR
64	0.000087	0.11	1.00	96	100	4	0	1	1680008807053	ACTUATOR
65	0.000793	0.98	1.00	144	100	4	0	1	1680009413712	WHEEL CONT
66	0.000057	0.35	1.00	168	100	4	0	1	1680011951058	CNTRLPANEL
67	0.000093	0.26	1.00	216	100	1			1680010850595	RECEPTABLE
68	0.003220	0.00	0.00	0	100	36	4	6	2620008091344	TIRE NLG
69	0.001294	0.00	0.00	0	100	60	4	10	2620010918257	TIRE
70	0.003921	0.93	1.00	144	100	6			2835000766472	ADAPTER
71	0.001567	0.06	1.00	192	100	12			2835000766499	VALVE SHUT
72	0.003048	0.59	1.00	216	100	4	0	1	2835008374869	SWITCH ASSY
73	0.000125	0.46	1.00	264	100	2			2840009831148	TANKASYOIL
74	0.003563	0.22	1.00	168	100	3	0	1	2910009081429	CONTROL FU
75	0.000067	0.46	1.00	120	100	2			2915000740439	VALVE
76	0.000243	0.58	1.00	168	100	3			2915001558098	VALVE ASSY
77	0.000105	0.19	1.00	192	100	6	0	1	2915007246003	ACTUATOR
78	0.000019	0.26	1.00	120	100	2			2915007884862	IMPLR PUMP
79	0.000034	0.26	1.00	168	100	3			2915007884863	IMPLR PUMP
80	0.000658	0.00	0.00	0	100	2			2915009017206	VAVLE
81	0.000193	0.04	1.00	144	100	3			2915009125993	CNTRL MAIN
82	0.000048	0.04	1.00	120	100	1			2915009913743	VALVE P+D
83	0.000067	0.34	1.00	216	100	1			2915010601265	VALVE
84	0.000036	0.14	1.00	168	100	2			2915011634373	VALVE FUEL
85	0.000385	0.03	1.00	192	100	6	0	1	2925004567627	EXCITER
86	0.000143	0.24	1.00	144	100	1			2925009391473	CABLE ASSY
87	0.000420	0.10	1.00	168	100	4	0	1	2935005731750	HEAT EXCHAN
88	0.000199	0.02	1.00	168	100	1			2935005736517	EXCHANGE
89	0.000031	0.06	1.00	96	100	1			2935008393707	COOLER ASSY
90	0.000116	0.86	1.00	144	100	1			2945009968330	FILTER ASSY
91	0.000123	0.24	1.00	144	100	1			2995000164939	MANIFOLD
92	0.000371	0.05	1.00	288	100	8	1	1	2995000707372	VALVE

93	0.000171	0.08	1.00	312	100	2			2995000879914	CONTROL
94	0.000995	0.53	1.00	216	100	10	1	1	2995002321491	CONTROL LH
95	0.000758	0.40	1.00	216	100	8	1	1	2995004356898	CONTROL RH
96	0.000180	0.07	1.00	192	100	6	0	1	2995004389890	ACT,AI
97	0.000270	0.07	1.00	144	100	6	0	1	2995004921489	STARTER
98	0.000410	0.08	1.00	192	100	11	1	2	2995007565840	CONTROL
99	0.000111	0.20	1.00	96	100	2			2995007599072	REGULATOR
100	0.000081	0.23	1.00	120	100	1			2995008691858	VALVECHECK
101	0.000084	0.04	1.00	336	100	4	0	1	2995009112615	ACTUATOR
102	0.000401	0.06	1.00	168	100	11	1	2	2995009742847	VALVE ASSY
103	0.000014	0.36	1.00	168	100	2			2995009914153	VALVE ASSY
104	0.000309	0.96	1.00	120	100	2			4140001049714	FAN COOLING
105	0.000179	0.78	1.00	168	100	2			4140007862928	FAN
106	0.000272	0.16	1.00	168	100	5	0	1	4320000513137	PUMP
107	0.000258	0.13	1.00	192	100	4	0	1	4320001521488	PUMP ASSY
108	0.000238	0.22	1.00	168	100	1			4320006314859	PUMP ASSY
109	0.000169	0.04	1.00	216	100	2			4320007020269	PUMP
110	0.000076	0.14	1.00	96	100	2			4320007564988	PUMP
111	0.000057	0.04	1.00	384	100	1			4320009171083	PUMP FUEL
112	0.000026	0.08	1.00	168	100	1			4320009438325	PUMP MAIN
113	0.000548	0.04	1.00	96	100	11	1	2	4320009995363	PUMP
114	0.000041	0.39	1.00	120	100	1			4810000152137	VALVE
115	0.000048	0.58	1.00	144	100	1			4810000547095	VALVE
116	0.000092	0.68	1.00	192	100	4	0	1	4810000898324	VALVE
117	0.000247	0.52	1.00	168	100	4	0	1	4810005736461	VALVE
118	0.000118	0.09	1.00	216	100	4	0	1	4810007572345	VALVE
119	0.000252	0.34	1.00	144	100	5	0	1	4810007961672	VALVE
120	0.000199	0.59	1.00	144	100	4	0	1	4810007961680	VALVE
121	0.000381	0.55	1.00	216	100	6	0	1	4810007961683	VALVE
122	0.000162	0.51	1.00	144	100	1			4810008686547	VALVE
123	0.000319	0.68	1.00	120	100	2			4810009417403	VALVE
124	0.000599	0.16	1.00	216	100	9	1	1	4820007596907	REGULATOR
125	0.000669	0.84	1.00	168	100	6	0	1	5821000192704	CPLRANT
126	0.001867	0.91	1.00	144	100	10	1	1	5821007646428	CONTROL
127	0.000115	0.80	1.00	120	100	1			5821007646428	ARREST OR
128	0.000348	0.43	1.00	144	100	4	0	1	5821008679247	AMPLIFIER
129	0.002568	0.89	1.00	168	100	45	4	8	5821008932906	RTUNIT
130	0.006931	0.77	1.00	120	100	6	0	1	5821009160057	RECTRNSMTR
131	0.000591	0.64	1.00	96	100	4	0	1	5821009812468	CONTROL
132	0.001694	0.88	1.00	144	100	2			5821010621019	RT1300REC
133	0.000308	0.24	1.00	120	100	2			5821011136476	CONTROL
134	0.002252	0.97	1.00	120	100	5	0	1	5821011369024	RT1168REC
135	0.002160	0.97	1.00	96	100	10	1	1	5821011376301	RECRT1168
136	0.000436	0.96	1.00	72	100	5	0	1	5826009731914	CONTROL WH
137	0.000844	0.88	1.00	96	100	11	1	2	5826009731916	RECEIVER
138	0.000756	0.97	1.00	96	100	5	1	1	5826009902332	RECR 51V4A
139	0.000364	0.82	1.00	96	100	3			5826010121919	CNTRL PANEL
140	0.001110	0.88	1.00	120	100	8	1	1	5826010121938	RT 1159A
141	0.000336	0.83	1.00	96	100	3			5826010124864	MX9577
142	0.000078	0.85	1.00	144	100	5	0	1	5831005235328	CONTROL
143	0.000078	0.85	1.00	144	100	2			5831005391714	C6567 CONT
144	0.001194	0.16	1.00	96	100	3			5841001687659	INDICATOR
145	0.002505	0.95	1.00	120	100	10	1	1	5841004120447	RECEIVER
146	0.000650	0.50	1.00	144	100	5	0	1	5841010890737	ANTENNA

147	0.000408	0.95	1.00	120	100	3			5841010891022	CONTROL
148	0.001821	0.95	1.00	120	100	11	1	2	5841010891064	INDICATOR
149	0.002205	0.92	1.00	144	100	15	2	2	5841010918929	RECTRANS
150	0.001000	0.10	1.00	168	100	2			5841011423767	CONTROL
151	0.004000	0.25	1.00	96	100	2			5841011423785	INDICATOR
152	0.000294	0.80	1.00	288	100	1			5841011435358	RACK
153	0.000587	0.90	1.00	72	100	4			5841011435474	CODERDECO
154	0.000200	0.00	1.00	168	100	1			5841011435778	CNTRL UNIT
155	0.002500	0.78	1.00	72	100	4			5841011435910	ANTENNA PD
156	0.002000	0.92	1.00	144	100	4			5841011435912	RECEIVER
157	0.002486	0.97	1.00	120	100	24	2	4	5895000894521	RT731APX64
158	0.000061	0.07	1.00	216	100	2			5930000661738	SWITCH ASY
159	0.001406	0.89	1.00	144	100	11	1	2	5985007236740	CONTROL
160	0.000110	0.11	1.00	72	100	2			6105009609879	MOTOR AC
161	0.000189	0.74	1.00	216	100	2			6110000712545	PANEL
162	0.000022	0.68	1.00	144	100	1			6110006898622	REGULATOR
163	0.000484	0.79	1.00	192	100	4	0	1	6110007325543	PANEL
164	0.000377	0.73	1.00	192	100	12	1	2	6110007931808	PANEL
165	0.000137	0.06	1.00	216	100	6	0	1	6110008682103	CONTROLLER
166	0.000545	0.50	1.00	168	100	4	0	1	6115007723552	GENERATOR
167	0.000038	0.08	1.00	72	100	1			6115007852060	GEN AC+DC
168	0.002226	0.96	1.00	168	100	3			6220000549503	LIGHT NVGN
169	0.003189	0.98	1.00	168	100	7	1	1	6220007026358	LIGHT NAV
170	0.002965	0.99	1.00	168	100	7	1	1	6220007060073	LIGHT NAV
171	0.000791	0.88	1.00	240	100	6	0	1	6220009023692	LIGHT LAND
172	0.000008	0.13	1.00	72	100	2			6340000737200	CONTROL
173	0.000661	0.05	1.00	72	100	3			6340007885797	DETECT
174	0.001051	0.85	1.00	144	100	4	0	1	6340010557374	COMPARITOR
175	0.000130	0.13	1.00	48	100	1			6605000743630	ACCEL VERT
176	0.000274	0.08	1.00	48	100	1			6605000743649	ACCEL HORZ
177	0.000089	0.91	1.00	72	100	1			6605001109499	MODE SELEC
178	0.005158	0.83	1.00	120	100	20	2	3	6605004583854	TPLC
179	0.000948	0.04	1.00	96	100	9	1	1	6605008745772	INDICATOR
180	0.000523	0.38	1.00	120	100	2			6605009992411	AMPLIFIER
181	0.000781	0.99	1.00	48	100	2			6605010177729	PICU
182	0.000087	1.00	1.00	48	100	1			6605010177730	NICU
183	0.001707	0.61	1.00	192	100	18	1	3	6605010182181	NAV UNIT
184	0.000962	0.78	1.00	96	100	11	1	2	6605010352009	CONTROL
185	0.000903	0.66	1.00	144	100	7	1	1	6610002517062	FLT DIR
186	0.002193	0.11	1.00	144	100	2			6610005506913	INDICATOR
187	0.000278	0.04	1.00	24	100	1			6610007270840	INDICATOR
188	0.000470	0.76	1.00	144	100	5	0	1	6610007753786	AMPLIFIER
189	0.000146	0.06	1.00	96	100	2			6610008103245	ALTIMETER
190	0.001447	0.04	1.00	96	100	12	1	2	6610008303587	ADI
191	0.000125	0.14	1.00	48	100	1			6610008676433	AMPLIFIER
192	0.000331	0.03	1.00	120	100	1			6610008868711	INDICATOR
193	0.000142	0.16	1.00	48	100	1			6610009036095	TRANSMITTE
194	0.000245	0.13	1.00	96	100	1			6610009056630	TRANSMITR
195	0.000213	0.08	1.00	48	100	1			6610009056630	TRANSMITR
196	0.004360	0.71	1.00	120	100	45	5	7	6610009063062	COMPUTER
197	0.000182	0.13	1.00	48	100	1			6610009150574	TRANSMI 60
198	0.000352	0.78	1.00	144	100	4	0	1	6610009861108	AMPLIFIER
199	0.001524	0.09	1.00	120	100	8	1	1	6610009927976	INDICATOR
200	0.001684	0.06	1.00	120	100	10	1	1	6610009927978	INDICATOR

201	0.004580	0.06	1.00	72	100	1			6615007557712	SENSOR WHL
202	0.001196	0.16	1.00	120	100	1			6615007635228	GYRO RATE
203	0.001577	0.92	1.00	120	100	9	1	1	6615008815068	CONTRPANEL
204	0.000200	0.39	1.00	144	100	1			6615010177727	COMP CONTR
205	0.002094	0.26	1.00	312	100	9	1	1	6615010177736	DISPL GYRO
206	0.001260	0.88	1.00	144	100	7	1	1	6615010181635	ECA
207	0.005907	0.84	1.00	144	100	21	2	3	6615011297151	AFCS COUPL
208	0.005373	0.82	1.00	144	100	22	2	4	6615011297152	ELEV COMP
209	0.003810	0.89	1.00	120	100	23	2	4	6615011787652	YAW COMP
210	0.001228	0.57	1.00	192	100	11	1	2	6620000721927	CONVERTOR
211	0.000158	0.04	1.00	48	100	5	0	1	6620007538885	CHANNEL FF
212	0.000263	0.04	1.00	48	100	6	0	1	6620007538888	CHANNEL EGT
213	0.000229	0.02	1.00	48	100	12	1	2	6620007538891	CHANNEL RPM
214	0.000237	0.06	1.00	72	100	2			6620009092079	IND AMPL
215	0.000573	0.04	1.00	120	100	11	1	2	6620009118706	TRANS EPR
216	0.002459	0.02	1.00	168	100	13	1	2	6620009421033	INDIC EPR
217	0.001153	0.11	1.00	96	100	12	1	2	6620009808040	IND TACH
218	0.001638	0.02	1.00	120	100	8	1	1	6620009808046	IND RATE FF
219	0.000558	0.03	1.00	120	100	10	1	1	6620009879076	TRANS RTFF
220	0.000272	0.10	1.00	264	100	1			6625001679864	FREQ METER
221	0.000434	0.10	1.00	72	100	3	0	1	6680007288764	INDICATOR
222	0.000367	0.05	1.00	72	100	4	0	1	6680007288765	INDICATOR
223	0.000349	0.02	1.00	96	100	3			6680007288767	INDICATOR
224	0.000254	0.02	1.00	72	100	2			6680007288768	INDICATOR
225	0.000226	0.02	1.00	48	100	2			6680007620454	INDICATOR
226	0.000448	0.16	1.00	120	100	2			6680009609932	INDICATOR
227	0.000537	0.11	1.00	144	100	1			6680009610036	INDICATOR
228	0.000293	0.09	1.00	96	100	2			6685005267864	TRANSMTR
229	0.000189	0.46	1.00	120	100	1			6685007573784	CONTROLLER
230	0.000444	0.95	1.00	72	100	1			6685007581575	SENSOR
231	0.000189	0.04	1.00	168	100	4	0	1	6685008091394	INDICATOR
232	0.000807	0.04	1.00	96	100	6	0	1	6685008776593	INDIC EGT
233	0.000051	0.10	1.00	96	100	1			6685009454960	IND TEMPER
234	0.000059	0.14	1.00	336	100	3			6685009454961	INDICATOR
235	0.000918	0.04	1.00	216	100	3			6685009454979	INDICATOR
236	0.000097	0.61	1.00	216	100	1			6685009593608	CONTROLLER

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VITA

Captain William J. Carolan was born 11 January 1954 in Brooklyn New York, and grew up in Seaford, Long Island. After graduating from Seaford High School in 1972, he attended the United States Air Force Academy, graduating in 1976 with a Bachelor ot Science in Management, and a commission in the United States Air Force. He completed pilot training at Williams AFB, Arizona in September 1977, and received an initial assignment flying C-141s at Norton AFB, California.

He remained at Norton until August 1980, when he was assigned overseas to fly CT-39s at Kadena AB, Japan. He returned to Norton in 1982 to resume flying C-141s, where he served duties as instructor pilot, squadron scheduler, squadron executive officer, and executive officer to the Deputy Commander for Operations. He is a Senior Pilot with more than 3000 flying hours.

Captain Carolan holds a Masters degree in Systems Management from the University of Southern California. In June 1985, he entered the Air Force Institute of Technology's School of Engineering, where he pursued a Masters degree in Operations Research. He is a member of the Omega Rho honor society for operations researchers.

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MODELING THE EFFECT OF SPARE PARTS LATERAL RESUPPLY ON STRATEGIC AIRLIFT CAPABILITY

I. Introduction

Research Problem

The current U.S. Air Force standard for capability assessment models based on spare part stockages is Rand Corporation's Dyna-METRIC. Due to the Military Airlift Command's (MAC) global mission and unique utilization of spare parts, MAC has been reluctant to accept this model. Dyna-METRIC does not work well for MAC mainly because the policy of lateral resupply between bases is not addressed. Lateral resupply is the process of acquiring a needed part from a nearby base, rather than ordering one from the depot. The logisticians at HQ MAC responsible for deciding spare part stockages claim that lateral resupply considerably reduces maintenance down-time, and therefore the capability figures produced by Dyna-METRIC underestimate their capability.

The problem to address first is whether lateral resupply is a significant factor in providing airlift capability. If determined to be significant, lateral resupply must be included in any capability assessment model based on spares.

BACKGROUND

When President Kennedy announced that a policy of flexible response would replace our country's previous policy of massive retaliation, MAC became a key player in the new strategy. Under Eisenhower's policy of massive retaliation, the emphasis was on nuclear weapons, and MAC's role was limited to the support of nuclear strike forces. A policy of flexible response, which we still operate under today, relies heavily on mobility, a concept of moving our troops and equipment anywhere and anytime to meet rapidly changing conditions (4:120). General Duane Cassidy, the current Commander-in-Chief of MAC (CINCMAC), contends

> In a world where wars are limited in time, airlift can be the stabilizing factor in preventing small crises from escalating into large conflicts (4:131).

According to General Gabriel, former USAF Chief of Staff,

> No Matter how good our equipment, tactics, and training, our forces are of little value if we cannot get them to the battle in time (9:130).

Airlift has played an important role in our military operations since World War II, but the real value of airlift was not realized until the 1973 Arab-Israeli War. In that war, U.S. cargo planes airlifted critical supplies to Israel,turning the tide of the war in favor of Israel. By contrast, the first U.S. ship dispatched with supplies took 14 days to arrive at a port in Israel, seven days after the cease fire (26:44)!

MAC's strategic airlift aircraft, the C-141 and C-5, are all between 15 and 21 years old, and are in constant need

of spare parts. Unfortunately, fiscal constraints have reduced the amount of money available to purchase spares. Major General Nugteren, Commander of Warner Robins Air Logistics Center (ALC), stated that spares funding for C-141s was only 12 percent of the required amount in 1980, increased to 58 percent in 1982, but decreased back down to 25% in 1983 (33:94). In 1984, a report by staff members of the House appropriations defense subcommittee said " The Air Force does not have sufficient spare parts to support a continued growth in flying hours, or to meet its wartime obligation ". The Air Force recognized the problem, but in the 1985 federal budget, their request for spare parts was cut by $1 billion (17:36). For the current 1987 budget, President Reagan is proposing a $644 million cut in spare parts funding. The result is a critical shortage of spare parts that could adversely affect our nation's ability to fight a protracted war.

General James Allen, a former Commander-in-Chief of MAC (CINCMAC) stated that a long-standing shortage of spare parts has prevented MAC from programming and planning high sustained aircraft utilization rates that are needed to support a variety of contingencies (34:176). When critical spare parts are not available to fix a broken aircraft, the aircraft remains grounded until the needed part can be obtained. A grounded aircraft means a lost sortie, and a lost sortie means degraded combat capability. General T.R. Milton (USAF Retired) recognized the importance of spare

parts when he noticed that budget priorities seem to always slight our airlift forces. He recommended that MAC make the most of what they have by using a large portion of their money for the purchase of spares, which will increase utilization rates of existing aircraft and enhance our readiness posture. (19:19)

Overall readiness encompasses several different resources: supply, fuel, munitions, aircraft, personnel, etc. A unit's overall readiness therefore would be the lowest figure attained by the respective resource categories (13:2). Spare parts shortages are often the limiting factor used in assessing a Wing's combat readiness. Holck and Ticknor (1981), in an AFIT thesis, identified spare parts and airframes as the limiting factors in resupplying a NATO war.

Combat readiness figures are briefed all the way up the chain of command to Congress, and are used by the Air Force for budgeting, planning, problem identification, and unit ratings. At the highest level, Congress needs those capability figures to justify defense spending to the American people. At the next level down, the Air Staff and Office of Secretary of Defense use the information to define requirements and defend funding requests to Congress. At the lowest level, capability assessments are needed by operational commanders so they can efficiently allocate their limited resources (23:1). MAC needs a tool that can accurately assess capability based on availability of spare parts.

Research Objectives

The primary objective of this thesis is to analyze the effect of lateral resupply on strategic airlift capability assessment. The hypothesis is that incorporating lateral resupply in a model increases airlift capability figures significantly. Since lateral resupply is actually used by MAC to provide needed spares, model results would more accurately reflect MAC's airlift capability.

A secondary objective of this research is to develop a model which can be used by MAC to obtain capability assessment figures with respect to current or proposed levels of spares.

Research Questions

1. Given a realistic strategic airlift scenario and authorized levels of spare parts, does a policy of lateral resupply significantly increase capability figures?

2. Can a model be developed for use by HQ MAC logisticians to accurately measure MAC's wartime airlift capability relevant to spare parts stockages?

Scope

An actual wartime Pacific theater scenario (unclassified), provided by MAC/LGSWR depicts a realistic operation of strategic aircraft during a war. A Pacific scenario is characterized by longer flight legs and resupply times, as compared to a NATO scenario, where European bases can be reached in a single eight hour flight from a stateside C-141 base. A Pacific scenario was chosen because longer

flight times result in more aircraft part failures, and therefore there is more repair and supply activity to analyze.

The peacetime operation of strategic airlift is not modeled since the subject of interest to Air Force leaders, Congress, and the American public, is the capability of our forces to fight a war if the need arises. Logisticians must predict how the existing stock of spares will suffice during a more stressful wartime environment, and determine what additional parts, if any, are needed (25:V).

Although the C-141 Starlifter is the only aircraft modeled, other aircraft in the scenario such as the C-5 and C-130 could also be modeled using different parts data, stockages, and sorties flown. Since parts between aircraft are generally not interchangeable, modeling a single type aircraft independently does not degrade the accuracy of the results.

II. LITERATURE REVIEW

Overview

The review begins with a discussion of basic inventory theory for recoverable spares, emphasizing the process of parts failing and getting repaired. In section two, various performance measures are presented, which are based on the availability of spare parts. Here, the relationship between inventory theory and capability assessment is established. The third section lays the foundation for inventory modeling by discussing the poisson process of part failures. Section four covers a powerful theorem used extensively in certain inventory models known as Palm's theorem. This sets the stage for the final section, which reviews the development of recoverable spare parts models, with emphasis on military applications.

RECOVERABLE SPARE PARTS INVENTORY THEORY

This research deals with recoverable, or repairable spare parts. The other type of spare parts is consumables, which will not be examined in this paper. Consumables are expendable items, not subject to repair.

Sophisticated and expensive aircraft designs provide incentive to design parts which can be easily removed and replaced, where the damaged part is then repaired as quickly as possible and reused (12:1). If the part can be repaired at the base where the failure occurred, the part is repaired locally and added to the inventory. If the local base cannot repair the failed item, it is sent to the depot for repair.

Meanwhile, the local base inventory is checked for a replacement part, and if they have the part in stock, it is installed on the aircraft, and the aircraft is once again fully mission capable (FMC). If a search of the base inventory shows that they are out of stock for that part, an order is placed at the depot. If the depot inventory contains the requested part, that part can be shipped immediately to the requestor. If the depot does not have the part on-hand, the plane must wait for the first available part to reappear in base stock, either through base repair or depot shipment (21:473).

An additional policy used by the MAC is to request the desired part from a nearby base before ordering from the depot. This concept is called lateral resupply, and it saves MAC precious time in the repair of their aircraft (5).

From the above process description, it can be readily seen that there are three main factors that affect the length of time an aircraft must wait to get fixed: inventory levels at both the bases and the depot, demand for the part, and repair time. Inventory levels will be discussed in the next paragraph. The demand for a part is analogous to its failure rate, if one assumes that a replacement is demanded every time a part fails. The higher the failure rate, the larger the quantity of parts in the repair cycle. Repair time at the base level consists of just the time required at the base repair shop. For an item that must be sent back to the depot, its repair cycle consists of shipment time to the

depot, repair time at the depot, and finally order and shipment time back to a base that places an order for that part (18:395).

The Air Force uses the classic (S-1,S) order policy for recoverable spare parts (30:311). This is a continuous review inventory policy, where S is the desired inventory level (9:391). When the inventory position (on hand plus on order minus back orders) drops below S-1, an order is placed to bring the level back up to S. This is commonly called a one-for-one ordering policy, since you place an order of one item every time your inventory decreases by one (11:345).

PERFORMANCE MEASURES of EFFECTIVENESS

Measures of effectiveness enable Air Force leaders to make decisions relating to their parts inventory levels and service policies. Ideally, the measure should be compatible with measures of other resources, so that an overall assessment can be made of an organization's ability to perform its wartime mission. Some of the performance measures used in inventory models follow.

NUMBER of BACK ORDERS. This is the most traditional performance measurement in inventory models. A back order exists when there is an unfilled demand for a part at the base level. Notice that a back order can exist at a base which has the required part, but the repair on it is incomplete (29:126).

FILL RATE. This is the percentage of spare part demands that are filled by current stock levels (29:127). It can also be thought of as the probability that a part will be in stock when an order is placed. Using this performance measure, you would maximize your fill rate by concentrating all your supply at the base level. High fill rates are meaningless if the related weapons systems are not mission ready because they are waiting for spare parts. If every plane in the Wing was in need of just one part, the Wing would have a high fill rate because demands were met for all other parts, but the entire fleet of planes would be grounded!

READY RATE. This is the fraction of items that are not in back order. A problem with this measure is that a fraction of items does not measure the number of units back ordered on an item (29:127). It also does not tell you the number of aircraft that are grounded due to a back order (32:16). Once again, if the entire fleet is grounded awaiting one type of part, the ready rate could be high, but the capability is zero.

NOT MISSION CAPABLE SUPPLY (NMCS). This measurement accounts for the number of aircraft not operational due to lack of spares. To calculate the probable number of available aircraft to fly a mission, you simply take 1 - NMCS. This complementary measure can be thought of as aircraft availability (15:10). The number of available and fully mission capable (FMC) aircraft is a good measure of a

flying Wing's ability to perform the mission, and accordingly, the performance measure used in this research paper is percentage of aircraft FMC.

THE POISSON PROCESS

The poisson process is widely used to model arrival processes. An arrival can actually be any occurrence at a point in time. Arrivals could represent people coming into a bank, telephone calls coming into a switch board, or, in the field of reliability, the occurrence of a part failing. Coinciding with a part failing, there is a demand for a replacement part. Poisson processes are attractive to use in models since past performance of a system is not considered, and the variance is equal to the mean, alleviating the problem of computing a separate variance (7:70).

To qualify as a poisson process, the independent increment property must first be satisfied. If N is the number of arrivals, then an arrival process is a poisson process if $(N_{t+s} - N_t)$ in the interval (t,t+s) depends only on s and not on t. This says that the number of arrivals should be independent of any prior arrival, ie., arrivals between time t and t + s should be independent of arrivals prior to time t. To calculate the expected number of arrivals during (t,t+s) we use $E[N_{t+s} - N_t | N_u ; u<t] = \lambda s$, where λ is the arrival rate. In essence then, the expectation of the next arrival is a constant (λ) times the length of the interval in question (7:76-77). A lemma of the poisson process states that $P\{N_t = 0\} = e^{-\lambda t}$, which says that

the probability of not having an arrival is $e^{-\lambda t}$ (7:72). The complement would state that the probability of having an arrival is $(1 - e^{-\lambda t})$. For any n > 0, $P\{T_{n+1} - T_n \leq t\} = 1 - e^{-\lambda t}$ which says that interarrival times $(T_1, T_2 - T_1, T_3 - T_2 \ldots)$ are independent and identically distributed random variables with an exponential distribution $1 - e^{-\lambda t}$ and a probability density function of $\lambda e^{-\lambda t}$. Since for a non-negative random variable X, $E[X] = \int_0^\infty P\{X > t\}\,dt$ (7:24), we can substitute $T_{n+1} - T_n$ for X to calculate the expected value of an interarrival time:

$$E[T_{n+1} - T_n] = \int_0^\infty P\{T_{n+1} - T_n > t\}\,dt = \int_0^\infty e^{-\lambda t}\,dt = 1/\lambda.$$

For aircraft part failures, $(1 - e^{-\lambda t})$ would be the probability of a part failing at or prior to time t, where λ represents the failure rate. Stated in equation form, $P(T \leq t) = 1 - e^{-\lambda t}$, where T = time between failures.

Another key condition of the poisson process is called the stationarity axiom, which states that for any t, s > 0, the distribution of $N_{t+s} - N_t$ is independent of t. Suppose that A and B are disjoint time intervals, where A = (t,t+a) and B = (s,s+b). Then N_A and N_B are independent random variables with poisson distributions and the expected number of arrivals ($E[N_A]$) equals λa, and $E[N_B] = \lambda b$. If C = (t+a,t+a+b), the stationarity axiom says that N_B and N_C have the same distribution, and so $N_B + N_C$ has the same distribution as $N_A + N_C$. The number of arrivals in A plus the number of arrivals in C is just the number of arrivals in (t,t+a+b), which has a poisson distribution with $E[N_A + N_C] = \lambda(a+b)$. Since $N_A + N_C$ has the same distribution as $N_A + N_B$

then $N_A + N_B$ also has a poisson distribution with $E[N_A + N_B] = \lambda(a+b)$ (7:77). Applying the concept to the poisson failure rate of spare parts, if plane A flies for two hours, and $\lambda_1 = .05$ for part 1, then the probability of part 1 not failing at the end of that flight is $e^{-(.05)(2)}$ or .9048. If plane B flies 2 legs of one hour each, the probability of part 1 not failing at the end of each leg is $e^{-(.05)(1)}$ or .9512. Since the individual flights are independent events, the calculated probability of the part not failing after the two legs is (.9512)(.9512) = .9048, which is the same success probability faced by plane A. This assumes that plane B can be repaired at the first base so that it can fly the second leg. This allows modeling multiple legs as though they are one leg composed of the sum of the individual legs.

The superposition of poisson processes permits the combination of separate and independent poisson processes with different failure rates (7:87). Applied to aircraft parts, if two parts fail independently according to a poisson process at rates λ_1 and λ_2, then the total failure process is also poisson with failure rate $\lambda_1 + \lambda_2$. With k total parts on the plane, the total probability of experiencing no failures up to time t is $e^{-(\lambda_1 + \lambda_2 + \lambda_3 + \ldots \lambda_k)(t)}$.

A compound poisson process varies by random amounts at each arrival time of a poisson process. Not only is the time between failures represented by a poisson process (exponential distribution), but the number of failures at each failure time also forms a poisson process, allowing for

multiple failures at an instant in time (7:92). The widely used Dyna-METRIC model uses the compound poisson process to compute the expected number of parts in the pipelines of a repair/inventory process.

Palm's Theorem

Palm's theorem dates back to 1938, but is still used extensively in inventory theory. Stated simply, if it can be assumed that repair time is independent of the failure process, and that ample service exists at the repair facility, then the quantity of parts in the resupply pipeline assumes a poisson probability distribution with the mean equal to the product of the average failure rate (λ), and average repair time (r) (13:7). Ample service implies that there is no queuing for repair. All arriving parts are serviced immediately. Intuitively, ample service does not appear to be a valid assumption, especially during a surge period precipitated by war. Increased flying activity would result in an increased number of failed parts, possibly resulting in backlogs at the repair depot. Manpower and/or test equipment might become overloaded.

To test the assumption of ample service, Gross (1982) conducted a study to see how fill rates, backorders and safety levels are affected if one assumes unlimited repair capacity, when in fact the number of servers is limited. When allowing for only a limited number of servers, r consists of the service time plus an additional factor of the waiting time for service. His results showed that the

largest errors occurred when λr is large and the number of servers (c) few. Errors also appeared larger for higher desired fill rates.

For the spare parts model presented in this paper, the effect of assuming ample service is very small. When the model was run, on the average about 170 total parts were sent to the depot for repair. The 38 planes modeled represent about 1/6 of the total C-141 fleet. If we assume that the other C-141s are engaged in similar activities during this 30 day scenario, a total of 170 X 6 = 1020 parts would be sent to depot repair. With 236 different parts, an average of 1020/236 = 4.3 of each type are sent to the depot. If there is a single server to repair each different type of part, over 30 days, parts arrive to him at a rate (λ) of 4.3/720 = .006 per hour. By using the highest repair time of 144 hours, λr = .864. Using the graphs constructed by Gross, a desired fill rate of 95%, and only one server, the ratio of required safety stock assuming ample service, versus required safety stock with one server, was .85. Also, at a desired fill rate of 85%, the expected increase in backorders caused by using c = 1 instead of infinity was only 5%. When c is increased to three servers, both measures show no difference between results obtained with and without the ample service assumption. These results obtained by Gross support the use of Palm's theorem in inventory modeling, and provide justification for its use in the model presented in this paper.

HISTORICAL PERSPECTIVE of SPARE PARTS INVENTORY MODELS

Deterministic inventory models were first developed in 1915 by two individuals working independently. Harris developed the Economic Order Quantity Model, and Wilson developed the Wilson Lot Size Formula, both of which were very similar (11:344). Stochastic inventory models had their roots during the 1950's, but it was not until the 1970's that the advent of computers allowed the development of stochastic models to flourish (11:345). The following review of recoverable spares inventory models begins with the Multi-Echelon Technique for Recoverable Item Control (METRIC) model developed in 1968.

METRIC. The basis for the METRIC model was established in the classic paper by Feeney and Sherbrooke in 1966. They took the continuous review policy and used it for a special case of one-for-one ordering when dealing with expensive and infrequently demanded parts. Sherbrooke expanded this concept in 1968 to include two echelons of repair, one at the base and at the depot (11:345). METRIC is a mathematical model transformed into a computer program used to determine base and depot stock levels for a fixed budget (29:123). The objective function is to minimize back orders on recoverable spares for all bases with the same type of aircraft (29:126). Depot back orders are considered only indirectly since a depot back order extends the length of a base back order (21:473). To calculate the demand for each item, Sherbrooke used a steady state compound poisson distribution,

which cannot account for surges in demand (29:131). Other key assumptions in the model include:

(1) All items are equally essential.
(2) There is no waiting for service at the repair facility (Palm's Theorem).
(3) No parts are condemned or scrapped.
(4) Lateral supply between bases is ignored (29:130).

In 1973, Muckstadt developed an enhanced version called Mod-METRIC, which eliminated the need to assume all parts equally essential.

MOD-METRIC. The difference between Mod-METRIC and METRIC is Muckstadt's use of a hierarchical or indentured parts structure (21:472). A policy that just tries to minimize the number of back orders will tend to fill the inventory with inexpensive components, where all parts are considered equally essential (32:20). With Mod-METRIC, Muckstadt takes into account the fact that an aircraft component is composed of several sub-components, and the impact of a sub-component back order on mission capability is very different than the impact of a component back order. A component is an item which can be removed from the aircraft and replaced with a similar item, and is called a line replaceable unit (LRU). The sub-component is removed from an LRU and replaced in an LRU in the repair shop, thus earning the name shop replaceable unit (SRU) (21:481).

Dyna-METRIC. Developed by RAND in 1980, Dyna-METRIC forecasts the quantity of each aircraft component in the repair cycle, based on the demands for the component in a wartime scenario. The model can then estimate how the

aircraft components affect aircraft availability. In addition, the components that most limit aircraft availability can be identified (25:vii). Dyna-METRIC's formulation, which differs from the previous two models, involves using a non-stationary poisson demand process in place of a steady-state process,which accounts for the dynamic behavior of the components. The model can account for the transient demands placed on component repair and inventory support caused by changes in sortie rates, mission changes, component repair resources, and other key factors (13:4). The key equation in Dyna-METRIC computes the expected pipeline size, or how many of each type part are in base repair, being shipped, or on order from the depot (25:11). Using Palm's theorem, the pipeline quantity assumes a poisson probability distribution with a mean equal to λr. Assumptions from METRIC, still inherent in Dyna-METRIC include unlimited repair capacity and no lateral resupply. In spite of the assumptions inherent in the mathematics of the model, its simplicity and low computer processing time makes Dyna-METRIC the pre-eminent inventory model for recoverable spares.

Vari-METRIC. Originally developed by Slay (1980) at the Logistics Management Institute (LMI), Vari-METRIC improves on the accuracy of estimating backorders. Graves (1985) showed that where METRIC results deviated from predicting optimum stock levels 11 percent of the time, Vari-METRIC only differed one percent of the time. The distinguishing

difference in Vari-METRIC is its use of a negative binomial distribution rather than poisson. This necessitates estimating a variance as well as a mean number of backorders. Graves and Sherbrooke assumed in their model that the variance is never less than the mean, although they could not prove it mathematically. Sherbrooke compares computational results of METRIC, Mod-METRIC, and Vari-METRIC against a "true value" obtained from simulation, and shows that vari-METRIC provides a much more accurate estimate of expected backorders (30). Once again, lateral resupply between bases at the same echelon is not modeled. Vari-METRIC has not yet been implemented by any Air Force agencies

<u>LOGISTICS COMPOSITE MODEL (LCOM)</u>. Unlike the METRIC series of models, which are analytical, LCOM is a simulation model. It is capable of performing detailed resource analysis of maintenance manpower, support equipment, and spares. In this simulation, the process of preparing an aircraft for a mission can be modeled in any level of detail desired by the user. For a given level of resources, the flying activity can be increased until a prescribed level of mission effectiveness can no longer be supported. An alternative approach is to set the flying activity level, and the resource levels can be altered until mission effectiveness is attained. As in the METRIC models, LCOM does not allow the user to model a lateral resupply network. The primary uses of the model are for manpower evaluations and system acquisition analysis (23:43).

SUMMARY

This literature review began with an introduction to the theory of recoverable spare parts, and Air Force inventory practices. The next section described various measures of performance employed by organizations in assessing their unit's capability to perform the Air Force mission. A discussion of the poisson process and Palm's theorem followed. The last section discussed how the two concepts of inventory theory and capability assessment have been incorporated into mathematical computer models that have been developed for the Air Force. The METRIC series of models are all analytical, and rely heavily on poisson demands and Palm's theorem dealing with infinite repair capacity, while the LCOM model is a simulation, consisting of a user specified sequence of operational activities. However, none of the models reviewed can account for a policy of lateral resupply between bases, a concept fundamental to MAC's supply and repair policies. Existing models are all base oriented, and MAC needs a model that is plane oriented, since MAC planes transit many bases.

III. MODEL DEVELOPMENT

Overview

Simulation affords the best opportunity to explicitly model the complex network structure of strategic airlift operations. Simulation is "the representation of the dynamic behavior of a system", and a simulation model is a "mathematical-logical representation of a system which can be exercised in an experimental fashion on a digital computer" (24:4). One of its many purposes is for performance assessment, which is its intended purpose in this model (24:5). The simulation language chosen is the Simulation Language for Alternative Modeling (SLAM), a fortran based language which allows flexible modeling through fortran subroutines. The model presented is a SLAM terminating simulation using networks and discrete event subroutines.

This chapter explains the formulation of the model to be used in this research. The key to a good model is a complete understanding of the system under investigation. The first section conveys this understanding by explaining in detail the MAC system of operations with respect to spare parts. All models contain inherent assumptions, and before using any model, these assumptions must be fully understood. The second section discusses the assumptions and limitations of this model. The last two sections deal with the verification and validation of the model. Verification is the process of ensuring that the model does what the programmer intended, whereas validation is the process of ensuring that system

reality is closely approximated by the model (24:10)

Modeling The MAC Strategic Airlift System

MAC Network System. MAC conducts missions world-wide in both peacetime and wartime. Unlike fighter aircraft of Tactical Air Command (TAC), MAC strategic airlift aircraft spend most of their time away from home station. With this mode of operation, aircraft maintenance and logistical support must occur at many different stateside and overseas bases. Maintenance squadrons, detachments, and Airlift Control Elements (ALCE) are either permanently or temporarily deployed to overseas locations for the purpose of servicing and repairing the transiting MAC aircraft.

Spare parts are stocked at selected bases to facilitate the replacement of failed parts. The total network system of spare parts is known as the MAC Forward Supply Support System (FSS). This starts with the Primary Supply Points (PSP) composed of the MAC bases on the East and West coasts of the United States. Examples are Norton AFB, Ca., and McGuire AFB, N.J. The PSPs support the Forward Supply Locations (FSLs) which are the main MAC overseas bases. Examples are Hickam AB, Hawaii, and Clark AB, Phillipines. The FSLs maintain a stock of spare parts which is essentially an extension of the Peacetime Operating Stock (POS) maintained at the PSPs. There are also a few remote bases classified as Forward Supply Points (FSP) which only maintain a few selected mission essential parts in stock. Examples are Richmond, Australia, and Diego Garcia, Indian Ocean. Parts at Richmond

are carried on the supply records of Hickam, and parts at Diego Garcia are carried by Clark (32:29-31).

Spare Parts. The purpose of maintaining inventories of spare parts, and providing for the repair of those parts, is to provide for the readiness and sustainability of our military forces (1:ii). Readiness is an indicator of the current availability of a weapon system, including the ability to deploy and employ without unacceptable delays (1:1-1). To measure readiness, one calculates the probability that an aircraft is not waiting for a failed part to be repaired or replaced by a good part. The category of spares which supports readiness is POS.

Sustainability reflects the staying power of our forces, or the ability of a weapon system to maintain a necessary level of combat activity (3). Usually, the necessary level is 30 days, after which we hope the industrial base of our country can gear up and provide resupply. To measure sustainability, a threat must first be defined which takes the form of a scenario, after which availability of spares is assessed. The category of spares which supports sustainability is the War Reserve Spares Kit (WRSK) (1:1-2).

The WRSK is an air transportable package of spares required to sustain planned wartime or contingency operation of a weapon system for 30 days pending resupply (36:2). The WRSK contains spares which are considered to be mission essential items. Consideration is also given to factors such as high failure rates and ease of removing and replacing the

part. The WRSK is designed to satisfy MAC's concept of sustainability, specifically for the first 30 days of a war.

There are six full WRSK kits for the C-141, one at each C-141 base, Travis, Norton, McChord, McGuire, Charleston, and one at Dover AFB, Del. Each WRSK is divided up into segments, which can be deployed to any overseas location at the outbreak of a war. The difference in the segments is based on the amount of activity it can support at a base, measured by the number of landings at that base. A base anticipating more landings than another base woulkd receive a larger portion of the WRSK. If the base receiving a WRSK segment already has spares stock, the WRSK stock is added to the base stock. Otherwise, the WRSK segment becomes the primary source of supply for that base (36:3). For the scenario used in this paper, the AA segment is deployed, which can support 75 landings. Bases that don't have any stock, and do not receive a WRSK segment, would be supported by the FSL stock, or if needed, the stock at the PSPs (5).

Since the purpose of this study is to assess wartime capabilities, the C-141 parts contained in the WRSK were chosen as the parts to model. The actual WRSK contains about 520 parts, but only 236 were included in the model. The reason is that MAC is in the process of converting the WRSK data into a new format for a new computer system. The only data available on WRSK attributes is from HQ AFLC's D029 listing, which does not match all the national stock numbers (NSN) of the actual WRSK parts. Consequently, 236 individual

parts were input into an external fortran file, each part possessing a unique demand rate, probability of base repair, and repair cycle time.

Demand rate is computed from historical data measuring the number of times a particular part was needed to fix an aircraft. This can be thought of as the failure rate of the part. The numbers listed in D029 are for demands per 100 hours of flying activity, so to convert everything to hours, the figures in the data set are the D029 numbers divided by 100.

The probability of base repair figures are listed as the number of times a part was repaired at base level per 100 hours of flying activity. Dividing this figure by the demand rate yields the probability that a part will be base repairable, given that the part failed. The resulting figures were input as part attributes in the data set.

The repair cycle time measures the amount of time required by the base repair shop to fix the part. The D029 measures time in days, so the data input was multiplied by 24 to convert the units to hours. Since no separate repair time was available for depot repair time, the repair cycle time was assumed to apply to the depot as well.

Other data relating to the WRSK were the quantities of each part in the WRSK, along with the quantities in each WRSK segment. These figures were obtained from HQ MAC/LGSWR, which is responsible for establishing WRSK composition for the C-141. Each C-141 home base received a full WRSK, and

three Korean bases, Osan (RKSO), Pohang (RKTH), and Yechon (RKTY) received the AA segments deployed from Travis, Norton, and McChord. The three Korean Bases were selected based upon anticipated activity for the given scenario.

The stock levels of WRSK parts at the FSLs would normally be available from HQ AFLC's Combat Supplies Management System (CSMS) listing, but inspection of the CSMS revealed that the stock numbers do not match up with the WRSK serial numbers. Once again this is due to a data format change in progress. For the purpose of this study, since it is known that the FSLs do maintain a POS of WRSK parts, the equivalent of a WRSK segment is placed at each FSL. After discussions with MAC logisticians, a TB segment was chosen as a representative stock level maintained at an FSL (6). A TB WRSK segment is designed to provide for 175 landings. The stock levels of individual WRSK parts at the depot at Warner Robbins is not easily obtained. The item manager would need to input into the computer each individual National Stock Number (NSN). That action was infeasible for this study. Recognizing that depot stock is not unlimited, but would probably contain at least as much as any other single base, I allocated the equivalent of one WRSK at the depot. Assuming Palm's theorem for ample service (as do all the METRIC models), components were repaired upon arrival at the depot.

Scenario. An unclassified scenario was provided by HQ MAC/LGSWR. The scenario involves a 30-day conflict in the Pacific region, with a focus in Korea. A total of 520

sorties, flown by 37 different aircraft was modeled. The plane numbers, sortie lengths, landing bases, and ground times were input into an external fortran file to be used by SLAM. Each of the five C-141 bases provided aircraft for the scenario. These bases were Norton, Travis, and McChord on the West coast, and McGuire and Charleston on the East coast. C-5 and C-130 aircraft were also part of the given scenario, but were not modeled.

After an aircraft lands at a base following a sortie, part failures are determined in the following manner. The probability of each part failing is computed using a poisson process. Failure probability is assumed dependent on time flown, and is independent of previous hours flown. The poisson process can be thought of as having no memory, where the past history of failures is ignored. The number of failures during the last sortie is independent of failures which occurred during previous sorties. The formula used is: $Prob(F) = 1 - e^{-\lambda t}$, where Prob(F) is the probability of the part failing, is the demand rate for the part, and t is the length of the last sortie (in hours). The graph in figure 1 shows the exponential probability distribution, where the verical axis is Prob(F) and the horizontal axis represents λt. If λ is .05 per hour and t is 10 hours, then the probability of the part failing is $1 - e^{-.5} = .393$. Demand rates for individual aircraft parts are much lower than .05, the highest demand for parts in the WRSK being about .006. For the same 10 hour flight, a λ of .005 results in a Prob(F)

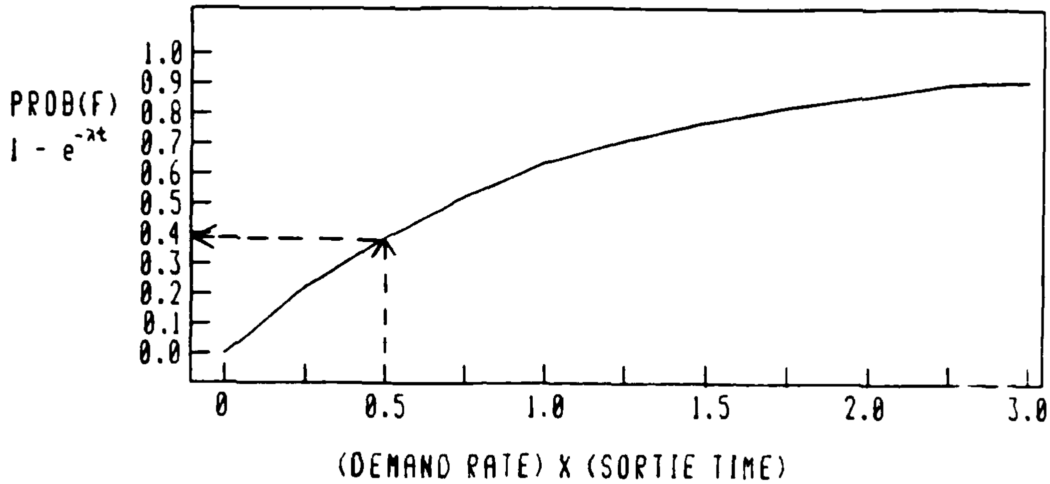

Figure 1.

Exponential Distribution Of Part Failures

of .049. For each part on the plane, a random draw is made from a random number generator, and compared to the Prob(F) for that part. If the number drawn is less than Prob(F), that part has failed, and is removed from the aircraft.

There are 42 different bases transited in the scenario, but stateside bases other than the PSPs are not included in the model, which leaves a total of 25 bases. Figure 2 shows the locations of the bases modeled. The FSLs in the scenario are Hickam, Elmendorf, Andersen, Clark, Kadena, and Yokota. Appendix C contains the 520 sorties flown including ground times, flight times, and arrival bases. The omission of the non-PSP stateside bases does not detract from model results since they would not have any WRSK segment or C-141 stock on hand. The flying activity into those bases was accounted

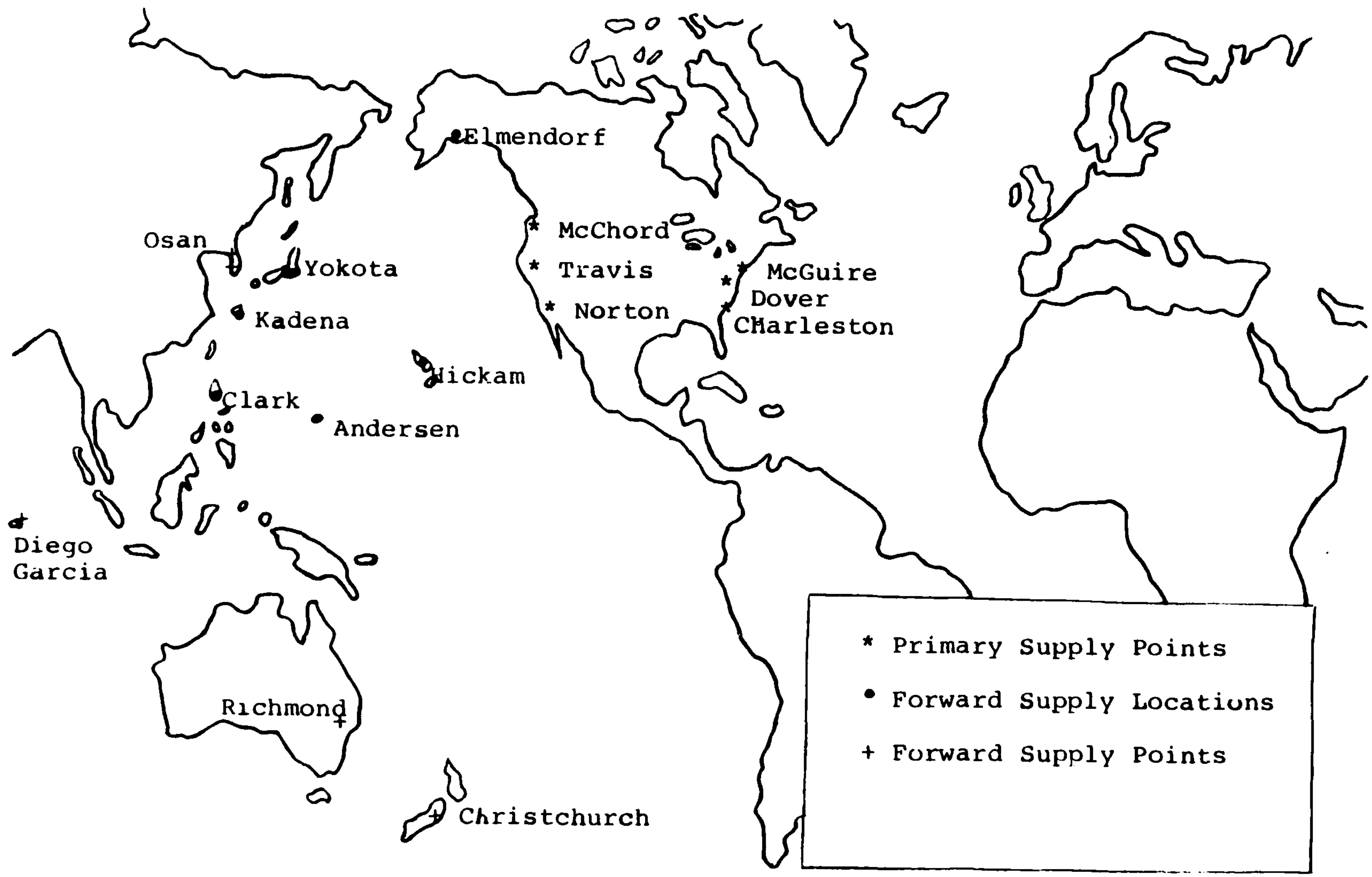

Figure 2. Base Locations

for by adding applicable flying hours to the sortie length into a modeled base. For example, if a plane flew from McChord to Offutt in 2 hours, and then Offutt to Travis in 3 hours, only one 5-hour sortie is recorded, with scheduled ground time at Offutt added to ground time at Travis. A plane flying one leg of four hours experiences the same part failure probability as a plane flying legs of two hours and three hours successively.

Repair and Replace Process. The sequence of events that occur following a part failure is depicted in figures 3, 4 and 5. A failed part removed from an aircraft undergoes a repair process to return the part back to the stock of available parts. Each part has a unique probability of base repair, ranging from 0 to 100%. A random draw is compared to this probability to determine if the part is base repairable. If not, the part is declared Not Repairable This Station (NRTS) and sent to the depot at Warner Robins for repair. A two-day delay is used in the model to get the part to the depot. Once at the depot, ample service is assumed, and the part is returned to depot stock after the repair cycle time. A condemnation rate of 0 is used in the model, which says that all parts arriving at the depot can be fixed. This is not entirely true, but condemnation rates for individual WRSK parts were not available from the depot unless the item manager made a separate computer inquiry for each part. If known, a condemnation rate, either universal or individual could easily be included in the model.

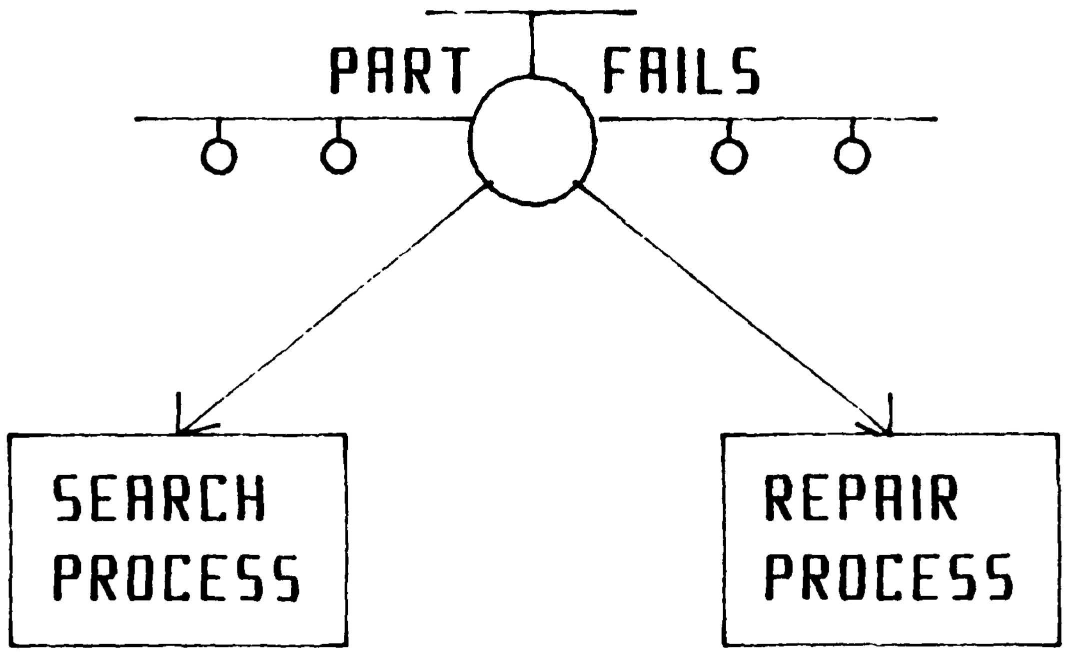

Figure 3. Parts Failure Process

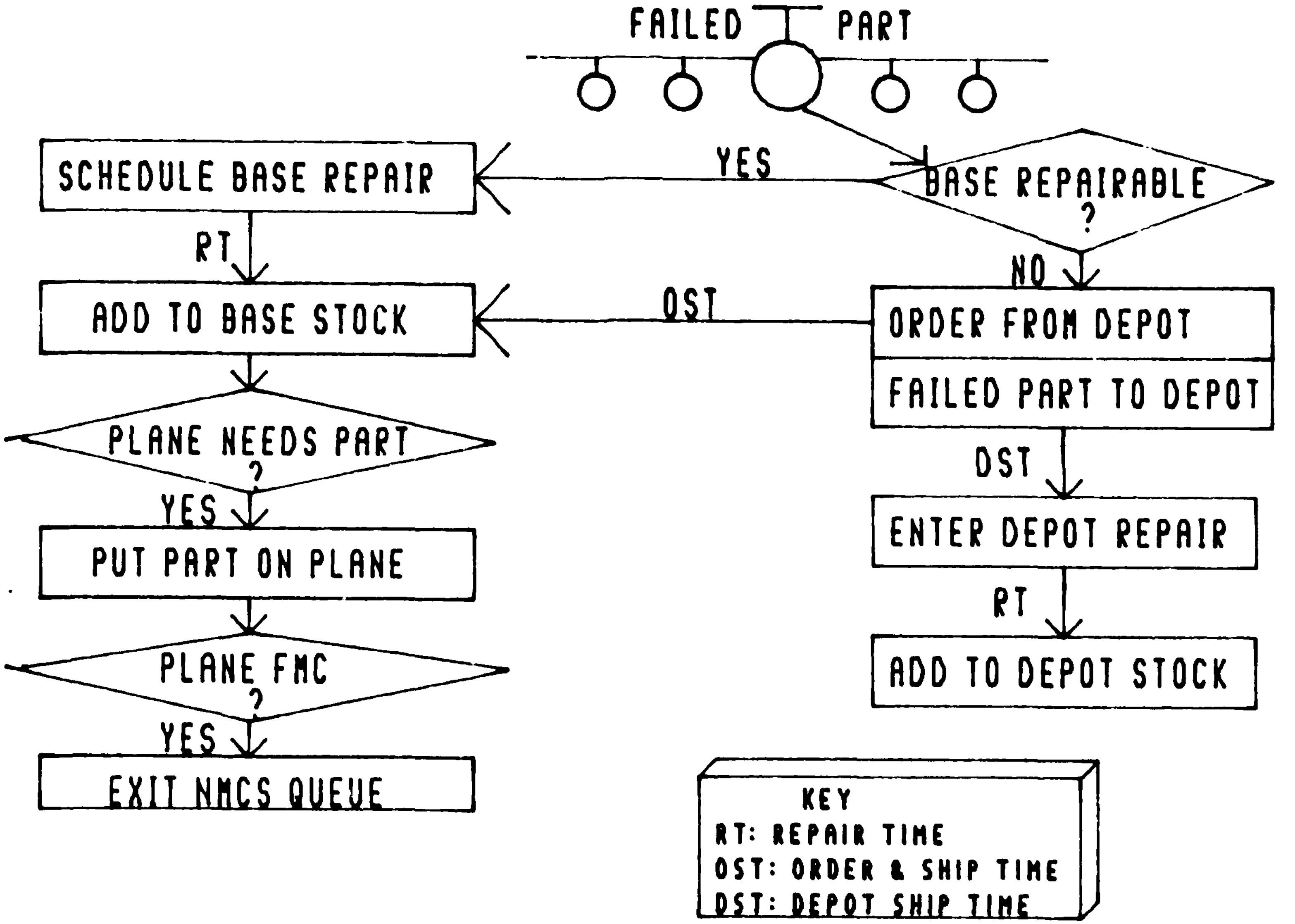

Figure 4. Parts Repair Process

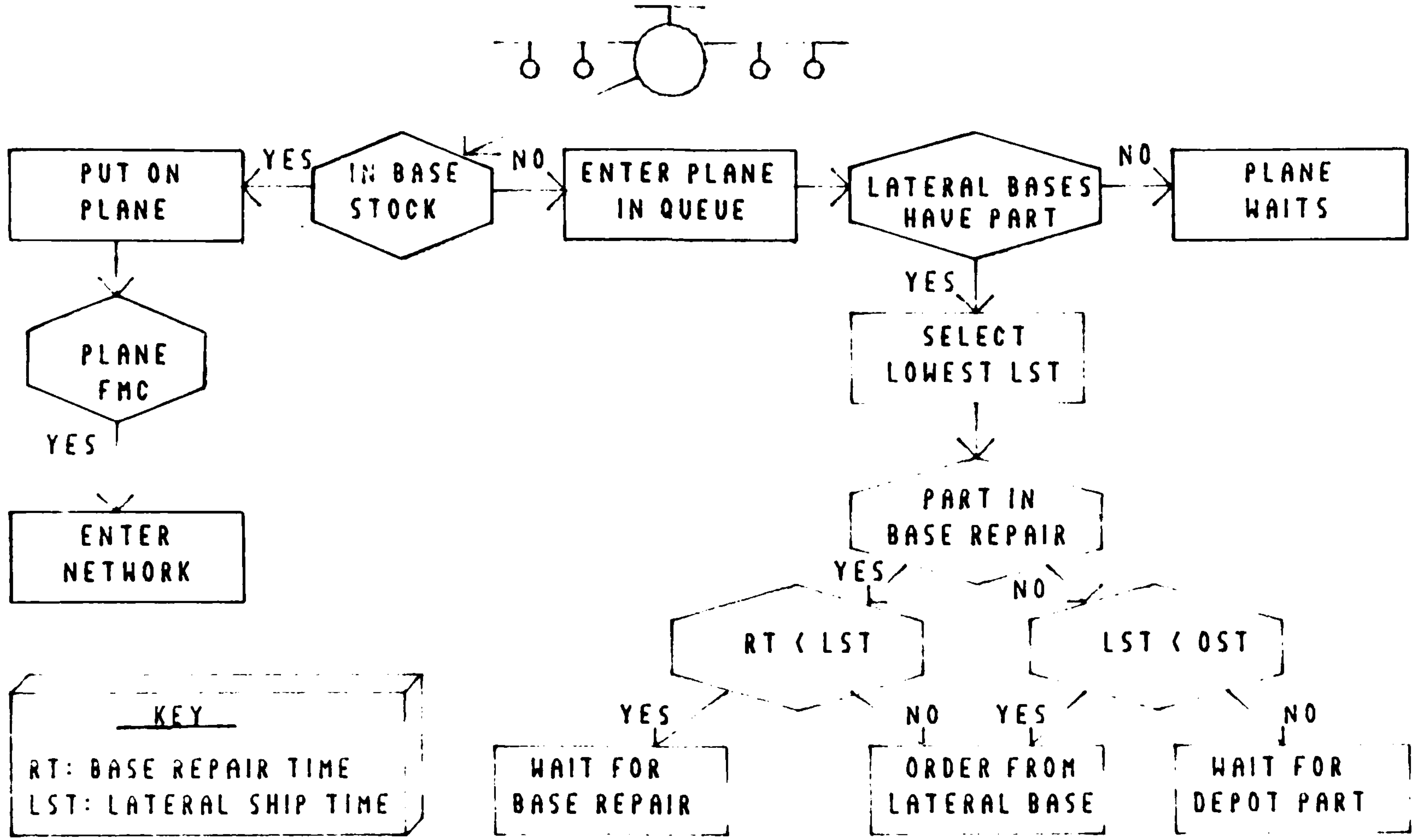

Figure 5. Parts Search Process

If a part is deemed base repairable, repair will take place locally if the plane is at one of the PSPs or FSLs, where repair facilities exist. The part is returned to base stock after the repair cycle time. Otherwise, the part is sent to the depot.

Coinciding with the repair process, a search is made to find a replacement for the failed part. The search begins with base stock, and if the part is in stock, the plane is immediately fixed and continues on its next mission. The model assumes that this activity can take place during the normal scheduled ground time.

When base stock does not have the part, a process called cannibalization is sometimes used. Cannibalization involves replacing a failed part with an operable part obtained from another aircraft. Cannibalization was purposely omitted from the model because of the nature of the wartime scenario. All planes are flying assigned missions, so no plane is sitting on the ground for any appreciable amount of time. If a plane with a takeoff time of 1200 takes a part from an FMC plane scheduled to depart at 1300, only an hour of down time is saved. A big factor that must also be considered when cannibalizing is the possibility of breaking the part when removing it from another aircraft. For this reason, the maintenance supervisor makes a judgment call of whether to cannibalize a particular part (5). Qualitative judgments cannot be explicitly modeled.

Lateral Resupply. In lieu of cannibalization, if base stock does not have the part, a search of neighboring bases is initiated. Lateral resupply is the process of transferring a part from a base with the part in stock, to a base in need of the part. In the general terms of inventory theory, it is the "lateral movement of assets within a given supply echelon from one site to another to satisfy supply shortages (31:iii)". This technique is fairly unique to MAC, since they operate into many different locations around the world, and also control the means to conduct the resupply mission. Other Commands normally request needed parts from the depot or a CIRF. However, TAC has recently recognized the benefits gained by using lateral resupply as evidenced by the creation of the European Distribution System (EDS) in 1984. This organization maintains a squadron of Sherpa aircraft solely dedicated to ferrying fighter aircraft parts between TAC bases in Europe. Air Force Wide, in 1985, about 8% of supply shortages affecting aircraft mission capability were satisfied through lateral resupply (31:1). When not satisfied through lateral resupply, demands were satisfied through either base stock, depot stock, or cannibalization (5).

If base A needs a particular part to fix a ramp, base A will search for the closest base part readily available. The definition of actually be the base that could provide the the shortest amount of time. For the

AD-A185 267 MODELING THE EFFECT OF SPARE PARTS LATERAL RESUPPLY ON 2/2
STRATEGIC AIRLIFT..(U) AIR FORCE INST OF TECH
WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.. W J CAROLAN
UNCLASSIFIED 10 DEC 86 AFIT/GOR/ENS/86D-2 F/G 15/5 NL

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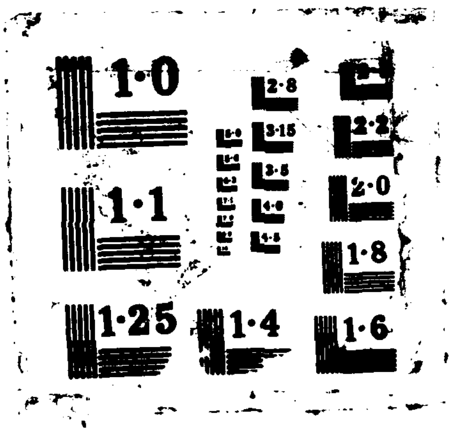
1·0
2·8
2·2
3·15
3·5
2·0
4·0
4·5
1·1
1·8
1·25
1·4
1·6

flying times between the bases were input into a 25 X 25 matrix in the network portion. The time was computed using actual leg times supplemented by the author's expert knowledge of the Pacific route structure. Where multiple stops would be required between bases, two hour ground times were used. Some routes in the scenario would require special routing due to political or geographical reasons. For example, a flight from Yokota AB, Japan to Diego Garcia in the Indian Ocean would necessitate a stop at Clark AB because Red Chinese airspace must be avoided.

The resulting resupply times represent the minimum time needed to fly a particular resupply mission. To allow time for processing the request and arranging for an aircraft to provide the lateral supply, a delay of 24 hours was added to all resupply times. This delay time is varied in the simulation experiment. A special mission is not generated specifically to carry a spare part. Rather, the part is put on the first available plane destined for the base in need of the part. The aircraft providing the lateral supply could be of any type or Service, and the airlift mission comes under the heading of opportune airlift (5). Since there is no way to know the schedules of all different aircraft during this scenario, the preceding method provides a reasonable estimate of the time involved in completing a lateral resupply.

A lateral search is first made of all the bases possessing the part in base stock. Among those bases, the closest one is selected to provide the lateral resupply.

After the lateral resupply time elapses, the part is put directly into Base A's stock instead of on the airplane because the plane may no longer be waiting for the part. The needy plane takes the first available part from any source: base repair, lateral resupply, or depot shipment. If Base B provided the part for Base A, Base B would order a replacement part from the depot, thus bringing its stock level back to the point it was prior to the lateral resupply.

Performance Measure. A meaningful measure of performance to the commander of a flying organization is the percentage of time aircraft are fully mission capable (FMC) to perform their mission. An FMC aircraft can perform any mission of any duration the aircraft is capable of. With respect to spare parts, this equates to (one minus the percentage of the fleet Not Mission Capable due to Supply (NMCS)). A performance measure of the number of sorties flown is not as useful for strategic aircraft since sortie durations can range from a few minutes up to 24 hours (with air refueling). Obviously, there are many other factors which determine whether or not a plane is FMC (fuel, maintenance personnel, etc.), but by assuming these other factors are always available, an isolated view can be taken of spare parts to determine the amount and distribution needed.

To calculate the NMCS performance measure in the model, there are repair queues at each transited base. If a needed WRSK part is not in base stock, the NMCS plane is placed in

the repair queue, and stays there until a part becomes available either through base repair, depot shipment, or lateral resupply. At the end of the 30-day scenario, the average length of each queue is interpreted as the average number of aircraft NMCS at that base. Summing these figures from each base yields the overall average number of aircraft NMCS for the scenario. Dividing that number by the number of aircraft flying the scenario gives the percentage of the fleet NMCS. The figure which would be briefed to the Commander is the probability of an aircraft being FMC during the scenario, which is just (1 - P(NMCS)).

Assumptions/Limitations.

(1) All other base resources which contribute to FMC aircraft are available at all locations.
(2) The 236 parts modeled represent the C-141 WRSK.
(3) Aircraft parts fail according to a poisson process, with failures a function of flight time.
(4) There is ample service at all repair facilities.
(5) The stock of WRSK parts at an FSL is the equivalent of the WRSK TB segment.
(6) Parts fail according to a poisson process, and as a function of time flown. There are a few aircraft systems, such as tires, that would seem to be fail as a function of landings rather than time, but time flown appears to be the best variable to predict part failures (32:34).
(7) Stateside bases, other than C-141 home bases, are ommitted from the model.
(8) There are no central intermediate repair facilities (CIRF) in the model. The presence of a CIRF in the simulation would cause the CIRF base to act like a base providing lateral resupply, with supply times to the various bases identical to the calculated lateral resupply times. Since the objective of this thesis is to compare a lateral resupply policy to a policy without lateral resupply, the CIRF was ommitted.

(9) Depot stock levels range from a low of one WRSK equivalent to a high of infinite supply.
(10) Lateral resupply times are calculated as (actual planned flight time) + (2 hours for each enroute ground time) + (an administrative delay time ranging from 1 day to 3 days).
(11) No planes deviate from assigned missions. If plane A becomes NMCS, no other plane picks up plane A's missions.
(12) There are a fixed number of planes flying the scenario, with no back-ups.
(13) The parts in depot stock are available only to the planes in the scenario. No other demands outside the scenario are placed at the depot.
(14) No cannibalization occurs.
(15) Crew availability is not considered. A crew is always available to fly an FMC plane.

Model Efficiency

The efficiency of a computer is measured by the amount of computer central processing unit (CPU) time required to run the program. For this model the CPU time used in each run ranged from 56 seconds to 1 minute 32 seconds. Much of that was used to make the random draws (122,720 if all 520 sorties are flown) when determining if a part failed. To increase efficiency, an alternative method is to make one draw (vice 236) each time a plane lands. The demand rate (λ) used to compute a Prob(F) of at least one part failing is the cumulative demand rate, calculated by summing the individual part demand rates. The reason we can do this is based on the superposition property of the poisson process explained in chapter II.

Each part's demand rate is expressed as a percentage of the cumulative demand rate, multiplied by Prob(F) to arrive at a probability of an individual part failing. When they

are all arranged into a cumulative probability distribution, each part's probability of failure covers a range on the distribution. The random number drawn will fall into one of the ranges, which determines which part has failed. For instance, if there are three parts total, with demand rates of .001, .003, and .002 respectively, the overall λ would be .006, and Prob(F) would be $1 - e^{-.006t}$. If t = 5 hours, Prob(F) = $1 - e^{-.03}$ = .0295. If a random draw was less than .0295, a part has failed and a determination must be made to find the failed part. Part 1's Prob(F) range would be from 0 to (.001/.006)(.0295) = .0049, part 2's range would be from .0049 to .0049 + (.003/.006)(.0295) = .01965, and part 3's range would be from .01965 to .01965 + (.002/.006)(.0295) = .0295. If the number drawn was .01500, part 2 would be declared the failed part.

The technique described above was tried in the research model, and CPU time was reduced to a low of 30 seconds and a high of 36 seconds, an increase in efficiency of about 50%. The drawback to this approach is that multiple failures cannot be modeled. When a failure is said to occur, only one part is singled out as the failed part. When parts were checked individually in the original model, multiple failures occurred fairly often, and in a few instances, there were as many as four failures on a single plane from a single sortie. The longer sorties have a higher probability of experiencing a failure, and so tend to be the ones having multiple failures.

Because of the shortcoming of not being able to account for multiple failures, the original method of determining part failures was employed. The superposition principle appears to be most useful in a scenario characterized by short sorties, where multiple failures are unlikely to occur if parts are tested individually. In short, if one is willing to accept the fact that only single part failures can be modeled, then the superposition principle can provide a significant increase in computer efficiency. The modeling method described in this section can easily be implemented.

Model Flexibility

The model is flexible enough to incorporate parameter changes fairly easily. The initialization subroutine in the discrete portion contains the parameter settings for lateral resupply policies, OST, administrative delay time, and depot stock level.

Separate data files are used for sortie information and aircraft part attributes. If one wishes to model different parts, and/or change part attributes, the procedure is quick and easy. Likewise, scenario changes can be made by creating a new sortie data set, which would only take about two man hours. If bases other than the 25 in this model are used, the array matrix of lateral resupply times between bases needs to be changed in the network portion of the model. This would take slightly longer since an expert would need to be consulted to determine minimum flight times between bases.

Verification

After a model is constructed, checks must be made to ascertain whether the intended actions are taking place when the model is run. During the development phase, print statements were used throughout the program to ensure thatvariables took on correct values, and proper activities were occurring. Since each plane was assigned a unique number, an individual plane could be tracked during its attempts to get a replacement for a failed part. After a part came into stock either through base repair, depot shipment or lateral resupply, verification was made that the right part went on the right plane.

When the model was completed, a check was made of the SLAM output to see if the numbers made sense. For example, a plane was released from the repair queue after it acquired all FMC parts. Since there are 236 different parts, no plane should ever end up with more than 236 entities. This was confirmed from the SLAM output. The queue lengths and waiting times were also examined to see if they made sense. A check of the number of failures for each type part revealed a direct correlation between high failure rates and high numbers of failures. The bases experiencing the most and/or longest flights were also experiencing the most part failures. This also made sense. In addition to the programmer conducting these checks, the thesis advisor also scrutinized the program code and output to verify the model.

Validation

Face Validity. A verified model is of no use if it does not depict reality to the extent that the output can be thought of as possible outcomes from the real system. The realistic depiction of MAC operations was acquired through numerous discussions with planners at HQ MAC, together with the author's experience as a MAC pilot.

Data Inputs. Actual current data was obtained when possible. The scenario flown, the numbers of aircraft involved, WRSK parts and part attributes are all real data inputs used by MAC planners. Where accurate data was unobtainable, high and low estimates were made, and sensitivity analysis was conducted to account for variations. Specifically, depot stock levels and lateral shipping delays were varied in the analysis.

Results. A comparison of results with other models is not possible since other models do not incorporate lateral resupply. Likewise, a check of results against reality is not possible when modeling the system with no lateral resupply, since lateral resupply does in fact take place. Although absolute results are scenario dependent, a comparison of different policies under the same scenario allows inferences to be drawn regarding system performance. If MAC's contention is correct, a lateral resupply policy should improve FMC figures. Validation of SLAM model results obtained through simulation runs are addressed in chapter V.

In addition, results obtained from Dyna-METRIC model runs (no lateral resupply) performed on a previous thesis will be looked at for validity comparisons.

Summary.

This chapter explained the development of the SLAM model. The first section covered the MAC system and spare parts cycle for strategic aircraft. A scenario was described, and a performance measure was established which will determine how well the system is performing given a certain set of variables. The model's efficiency measured in CPU time was discussed, along with a suggestion for efficiency improvement. The model's flexibility in terms of ease of use was also discussed. Some of the model assumptions were summarized, and the verification/validation procedures were covered. The next section takes the model developed herein, and designs an experiment to answer the research questions.

IV. Experimental Design

Overview

A statistical experimental design is a set of principles used to maximize information gained from an experiment for the purpose of quantifying the effect of independent variables on a response variable (2:472). These variables are the inputs for the model, such as decision variables, assumptions or parameters of random variables. The independent variables are called factors, and the values assigned to the factors are called levels. A treatment is a combination of factors set at a specified level, and the complete set of treatments for all factors and levels constitutes a factorial design. A factorial experiment determines the effects of the levels of each factor (main effects), as well as how each factor affects the response variable across levels of other factors (interactions). The first section in this chapter describes the factors and factor levels used in the experiment.

The minimum number of data points needed in an experiment is the product of the number of levels for each factor (28:296). Factorial design nomenclature stems from this calculation. An experiment with three factors at two levels is called a 2^3 factorial design. In simulation, additional data points are obtained by performing independent replications, which are simulation runs made with the same treatment, but with independent streams of random numbers for the various distributions in the model.

A tradeoff must be made between the cost of additional replications and the desired accuracy of the results. The second section of this chapter shows how this tradeoff was handled for the factorial experiment.

The sample mean ($\bar{X}_i$) derived for a treatment has a variance ($Var(\bar{X}_i)$) associated with it, which is a measure of the reliability that can be expected if the simulation experiment is repeatedly performed. Variance reduction techniques (VRT) attempt to reduce the estimated values of $Var(\bar{X}_i)$. The third section of this chapter discusses VRTs used in tnis experiment.

Factors & Factor Levels

When selecting the independent variables (factors) to include in a factorial experiment, it is important to keep in mind the objectives of the experiment. For this experiment, the main concern is the significance of incorporating a lateral resupply policy in recoverable spare parts managemen*. Therefore, factor A is a policy variable representing full utilization of the resupply concept. It is a qualitative variable in the respect that it is a policy either used or not used. However, since there is uncertainty with the amount of administrative delay time (ADT) incurred when shipping a part between lateral bases, a quantitative aspect was added. The factor level "with lateral resupply" was broken down into two distinct levels, one with an ADT of 72 hours, and the other with an ADT of 24 hours, representing

the high and medium levels respectively. The factor level "without lateral resupply" represents the low level.

Two other factors were added to the experiment to account for the uncertainty in their levels. Different levels of these factors might have an effect on the NMCS rate, either individually (main effects) or combined with other factors (interactions). Factor B is the Order and Shipping Time (OST) for the part. This is the period of time beginning when an order is placed at the depot, and ending when the part is delivered to the requesting base. The Air Force historically has used a 30-day OST in spare parts models operating during a wartime scenario. The reasoning for this is that the parts in a WRSK are designed to last for 30 days, without resupply. However, the intent of this model is to depict a realistic system, and during a war, resupply will occur (35). After conversations with the C-141 item manager at Warner Robins ALC, a realistic minimum OST was set at 7 days, which would be for the highest priority part (35). The high level was established by referring to the War Reserve Materiel Compendum, which allows the depot a 15-day OST for resupplying the Pacific bases.

Factor C is the stock level of C-141 WRSK parts at the depot. Actual levels change from day to day, and to obtain the quantity of each WRSK part at a specified point in time would require the item manager to interrogate the computer for each individual stock number, an infeasible task for this study. The uncertainty of the depot stock level provided

justification for including it as a factor for analysis. Experts on C-141 WRSK were consulted to obtain a low level for depot stock, and consensus was that the depot would possess at least the equivalent of a WRSK that a PSP would have. Actually, for some parts, the depot would have more, and for other parts the depot would have less. This is due to unanticipated demands for individual parts which accumulate or deplete inventories to undesirable levels (6). The high stock level was easier to set. An unlimited supply of WRSK parts was used, which is really what all the METRIC models assume (30:311). The quantity actually entered in the model was 100 for each part, which is more than enough. The most requests from the depot for any one stock number during the 30 day scenario was around 10. The effect of having an unlimited number of parts at the depot is to negate the effect of depot repair, since it doesn't matter when a part is repaired if requests for good parts are always fulfilled.

A summary of the three factors, along with their levels, is presented in Table I. The numbers -1, 0, and 1 represent low, medium, and high levels respectively. They are coded this way for simplicity when analyzing the effects with Statistical Analysis Systems (SAS).

Table I.
Factorial Design

LATERAL RESUPPLY(A)	OST(B) 7 DAYS: DEPOT LEVEL(C) WRSK	7 DAYS: INFINITE	15 DAYS: WRSK	15 DAYS: INFINITE
NONE	(-1,-1,-1)	(-1,-1,1)	(-1,1,-1)	(-1,1,1)
1 DAY	(0,-1,-1)	(0,-1,1)	(0,1,-1)	(0,1,-1)
3 DAYS	(1,-1,-1)	(1,-1,1)	(1,1,-1)	(1,1,1)

Accuracy Versus Sample Size

The number of data points (obtained by observations or simulation runs) required for a factorial experiment is the product of the number of levels for each factor used. For example, an experiment with four factors, each at three levels requires 3X3X3X3 = 3 = 81 data points. The factorial design used for the model in this research paper has one factor at three levels, and two factors at two levels. The number of required data points is therefore 3X2X2 = 12.

If one simulation run was performed for each treatment of 3X2X2 experiment, only 12 total runs would be required. However, with only one data point obtained for each treatment, there is no way to estimate experimental error, referred to in statistics as mean square error (MSE). If conditions dictate that only one observation can be obtained for each treatment (ie. limited computer time), then high

order interactions must be assumed negligible, and their mean squares are used to estimate experimental error (20:273-274). If available resources allow the experimenter to obtain several data points for each treatment, MSE can be estimated, and the accuracy of the results is increased. As the number of data points increases, the accuracy of the results also increases.

When estimating a performance measure through simulation, a specified accuracy can be attained either by increasing the number of replications or increasing the run length (2:439). Since this is a terminating simulation, and the run length is set at 30 days in order to assess capability during the first 30 days of a war, increasing replications becomes the method to employ. To determine the number of replications needed, three parameters must be specified, the desired accuracy (ϵ), the level of significance (α), and the standard error (S_e).

For this experiment, ϵ was obtained by considering the performance measure. Since the performance measure is the percentage of the 38 planes NMCS, an error of one plane makes a difference of 1/38, or 2.6%. The author felt that 2.6% error was acceptable for obtaining the NMCS figures. A difference of one plane would not affect the inferences drawn from the experiment, and therefore an ϵ of 1.0 was chosen.

The level of significance is discretionary, but typically experimenters use .10 or .05, which equates to confidence levels of 90% and 95% respectively ($100(1-\alpha)\%$). A

90% confidence level was chosen for determining the number of replications needed.

The S_0 was obtained by performing five replications of a specified treatment and using the sample variance as an initial estimate of variance (S_0^2). The standard error estimate is simply $\sqrt{S_0^2} = S_0$. Since there were 12 treatments to chose from, two sample tests were conducted from two different treatments, one with lateral resupply and one without. The higher S was then used as the standard error estimate, which would help ensure that point estimates obtained were within the error estimated.

The two selected treatments, along with the results of the trial runs are shown in Table II.

Table II.
Trial Simulation Runs

Replication	Trial 1 (-1,1,1)	Trial 2(0,-1,1)
1	22.35472	5.633265
2	21.80812	6.412014
3	20.67208	5.260069
4	20.34020	6.129375
5	21.53632	6.007500
Mean	21.342288	5.8884446
S_0	.8265932	.4489764

An initial estimate of the number of replication (R_0) is given by: $R_0 \geq (Z_{\alpha/2} S_0/\epsilon)^2$ where the Z value is found from the cumulative normal distribution tables. $Z_{(.10/2)} = 1.645$, and $R_0 \geq (1.645(.827)/1) = 1.85$, so R_0 must be at least 2 replications. Next we solve for the final sample size (R),

where R is the smallest integer satisfying $R \geq R_0$ and $R \geq (t_{\alpha/2, R-1} S_0 / \epsilon)^2$. Constructing a table such as the one in Table III, we can test the sample sizes greater than 2 by iterating one at a time.

Table 3.

Test For Required Replications

R	2	3	4
$(t_{\alpha/2, R-1})$	6.314	2.920	2.353
$(t_{\alpha/2, R-1} S_0/\epsilon)^2$	27.26	5.83	3.79

Since at R = 4 replications $R \geq 3.79$, we can say that four replications are sufficient to achieve the stated accuracy with 90% confidence

Variance Reduction

For this model, there are two random number generators used throughout the program. One is used each time a plane lands to determine if any parts have failed during that sortie. For the 236 parts on the plane, if all 520 sorties are flown, this equates to 236 X 520 = 122,720 random draws for each simulation run. The second random number generator is used to determine if a failed part is base repairable. Approximately 300 parts failed during one simulation run, so about 300 draws are made from this random number generator. The randomness of the numbers drawn introduces variability in the results from one run to the next.

Synchronized common random number streams (SCRNS) reduce the variance within the experiment (24:506). Each stochastic process, one for determining part failures and one for determining base repairable items, was assigned a separate random number by specifying different initial seed values. The same streams are then used for different treatments, which insures that the system behaves similarly when factor levels are changed. This assures that any changes in the performance measure is due to a change in factor levels, and not due to effects of changing random number streams. Each replication uses a different set of random number streams applied to all treatments, insuring that each replication across each treatment started from the same stochastic state.

Another VRT called antithetic sampling reduces variance by inducing a negative covariance between observations (24:506). This is accomplished by making two simulation runs to get one observation. The second run would use the negative value of the initial seed used in the first run. This procedure would require another 48 runs for the experiment in this paper. In addition, Kleijnen cautions against using common streams in conjunction with antithetic sampling, as a variance increase may actually occur (24:509). For these reasons, antithetic sampling was not used.

Summary

The experimental design chosen for this research is a 3X2X2 factorial, with factor "Lateral Resupply" at three

levels, "OST" at two levels, and "Depot Stock Level" at two levels. Statistical techniques were used to decide that four replications of each treatment would be sufficient to achieve an error rate of 2.7% with 90% confidence. Finally, variance reduction was accomplished by using synchronized common random number streams.

The next chapter discusses the results of the experiment, beginning with validation of simulation results, and ending with inferences that can be drawn from an analysis of variance (ANOVA).

V. Analysis of Results

Overview

Up to this point, the research has involved formulating a problem, conducting a review of relevant literature, building a model, and designing an experiment to use model results to answer the research questions. This chapter analyzes those results and interprets their meaning and relevance to the lateral resupply issue. The chapter is organized into three parts. First, a look at the SLAM output reveals whether the model is valid in predicting NMCS rates. Next, a statistical procedure called analysis of variance (ANOVA) is used to determine the significance of the factors in the experiment. Finally, a straightforward interpretation of the results is presented, with an answer to the first research question posed in chapter I.

Validation of SLAM Output

Validation is a process of increasing confidence to an acceptable level so that the inferences made from the model are correct for the actual system. A simulation model needs to be validated so it can used to provide some insight into the behavior of the system. Face validity was discussed in chapter III on model development. Validity in the context of this chapter deals with testing assumptions and the input-output transformations of the model.

A look at the SLAM summary report reveals quite a bit of information about the behavior of the system. There were 99 files or queues used in the model, and statistics on the numbers of entities in the files, as well as the amount of time entities spend in the files are printed on the Summary Report. Files 1 - 25 represent the 25 bases in the scenario, and the entities in the files are the WRSK parts. At the beginning of the scenario, parts were distributed among the bases according to the rationale described in chapter III. A check of the quantity of parts in each base file on the summary report confirms that the proper distribution of parts was made.

Files 26 - 50 represent the repair queues at each of the 25 bases, and form the basis for the performance measure of NMCS aircraft. Table IV shows the average number of planes NMCS at each of the 25 bases during the 30 day scenario. Column 2 is from a treatment with lateral resupply (AD = 1 day, OST = 7 days, limited depot stock), and column 3 is from a treatment without lateral resupply (OST = 7 days, limited depot stock). The bases consistently experiencing the largest average number in the queue are Yokota (RJTY), Hickam (PHNL), and Kadena (RODN). This makes sense, since more missions operated into Yokota and Kadena than any of the other bases in the scenario, and Hickam had a combination of many sorties of long duration. There were 77 sorties which terminated at Kadena, although most were only two hours in duration. There were 62 landings at Yokota, most from short

Table IV.

Average Number Of Planes NMCS during 30-Day Scenario

Base	W/ LATERAL RESUPPLY	W/O LATERAL RESUPPLY
KSUU	0.035	0.000
KTCM	0.036	0.000
KSBD	0.000	0.000
KWRI	0.000	0.000
KCHS	0.000	0.000
PAED	0.039	0.467
PGUA	0.114	0.167
PHNL	0.797	3.402
PWAK	0.000	0.000
RJTY	0.897	2.247
RODN	0.580	1.467
RPMK	0.515	0.233
RKTH	0.308	1.167
RKTY	0.482	0.927
RKSO	0.429	0.998
RJOI	0.211	0.700
RJTA	0.000	0.000
RJNK	0.069	0.467
RPMB	0.312	1.195
RKJK	0.167	0.330
RKJJ	0.069	0.698
RKTN	0.246	0.933
FJDJ	0.121	0.467
ASWM	0.172	0.233
ASRI	0.033	0.000
TOTAL	5.633	16.097

sorties also, although there were several flights in excess of 10 hours originating from Elmendorf or Hickam. Hickam saw 50 aircraft arrive, but all were sorties over five hours long. Since these three bases experienced the most and/or longest sorties, we would expect them to experience the most aircraft part failures, and when base stock eventually became depleted, planes would begin to back up in the repair queues waiting for parts.

As can be seen from the total NMCS figures, the policy with lateral resupply resulted in a lower number of planes NMCS, which is what we expected. The few instances where a base experienced more NMCS planes under a lateral resupply policy can be explained by the fact that fewer sorties were flown in the scenario without lateral resupply. The planes broke for longer periods of time, and were stuck at bases like Hickam, Yokota and Kadena, preventing them from flying the remainder of their missions. This phenomenom is most evident at Travis (KSUU) and McChord (KTCM), where the stock of parts depleted to a point causing NMCS aircraft under a lateral resupply policy, but not under a policy without lateral resupply.

A tabulated summary of overall NMCS rates for each treatment and replication in the experimental design is shown in Table V. In addition to lower NMCS figures when lateral resupply is used, increasing the administrative delay time from one day to three days caused the NMCS rate to increase.

Table V. Overall NMCS Rates

TREATMENT	LATSUPLY	OST	DEPOT	REP1	REP2	REP3	REP4
1	-1	-1	-1	16.1260	19.1652	18.0002	15.8155
2	-1	-1	1	16.0971	16.7760	17.8091	14.1686
3	-1	1	-1	22.3547	22.0872	20.2449	20.2703
4	-1	1	1	22.3547	21.8081	20.6721	20.3402
5	0	-1	-1	5.6333	6.8449	5.6563	6.3515
6	0	-1	1	5.6333	6.4120	5.2601	6.1294
7	0	1	-1	5.9372	7.5692	5.1496	6.2356
8	0	1	1	5.9372	7.4091	5.1496	6.2356
9	1	-1	-1	11.9855	14.3904	12.8587	11.7412
10	1	-1	1	12.1079	13.3116	12.5816	11.6667
11	1	1	-1	12.4372	13.4610	12.4363	12.3201
12	1	1	1	12.5383	13.1756	12.3326	12.3201

This is also to be expected since planes had to wait in the queue an additional two days for a lateral resupply.

Varying the depot stock level did not prove to be very significant. NMCS rates only decreased slightly, if at all, with the largest changes occurring with no lateral resupply. This makes sense because planes in that scenario had to rely solely on the depot for support when base stock could not provide the part.

Some of the NMCS rates seem high at first glance, since a result of 20 planes NMCS means that on the average over a 30 day scenario, 20 out of 38 planes (53%) are NMCS, not a very comforting thought to a MAC Commander. However, one must realize that a condition of no lateral resupply is really just a hypothetical situation that does not actually exist for MAC supply operations. Even the three day administrative delay time is unduly long, especially during the urgency of a war. In addition, the model does not account for cannibalization, and if cannibalization procedures had been used effectively, we would expect lower NMCS rates.

As large as the NMCS rates are with no lateral resupply, they still compare favorably with Dyna-METRIC results obtained by Stone and Wright in their 1984 thesis, where they attempted to model strategic airlift. Their results were broken down by base types, either POS, FSS, etc. Using a 30-day OST and DO29 data, for the stateside POS bases, the expected NMCS rate was 50% after 25 days, averaging about 30% over the 30 days. For the overseas FSS

bases, 100% of the fleet was NMCS after 25 days, and an average over the 30 days was around 80%. Stone and Wright also varied OST, but for this they used different demand rates for stateside and overseas bases. They accounted for the fact that sometimes failed parts overseas are not replaced because the crew feels that the plane can be flown home, where the demand for the part will actually occur. The result is higher demand rates at the home POS bases, and lower demand rates at the overseas bases. Under those conditions, a base with a TB segment of the WRSK (the same segment given to the FSL bases in the simulation scenario), a 14 day OST resulted in an average NMCS rate of about 40%, and a 7 day OST yielded a rate about 5% lower. Considering these results from a Dyna-METRIC run, the results obtained here under a "no lateral resupply" policy are not unreasonable.

By analyzing the simulation output, model results appear to be valid. The next section addresses the significance of the difference in overall NMCS rates between treatments.

ANOVA

The analysis of variance was conducted using PROC ANOVA on the SAS software package. The primary ANOVA outputs of interest in this thesis are the F tests of all effects in the MODEL statement. The F test from an ANOVA tests the null hypothesis that the means in a set are all equal. By specifying all one-way, two-way, and three-way interactions in the MODEL statement, the ANOVA output will show an F value for each combination of factors.

The F value (F^*) is compared to an F statistic taken from a statistical table. The degrees of freedom (ν_1, ν_2) must be specified as well as the level of significance (α). If $F^* < F(1-\alpha, \nu_1, \nu_2)$ then we conclude that no interaction is present. Otherwise, an interaction exists and is considered significant. The results from the experiment are shown in the ANOVA table in Table VI. If we use an α of .05, then the F statistic for treatments involving A is:

$$F(.95,2,36) = 3.29$$

and the F statistic for all others is:

$$F(.95,1,36) = 2.47$$

since significance occurs only when the values are greater than the F statistics computed above, the only significant effects are A main effects, B main effects, and the AB interaction effect.

Now that we know that factors A, B, and AB are significant, we would like to know at which levels of B are the means different for the three different lateral resupply levels. To accomplish this, multiple comparisons of the means was performed by using the Duncan multiple range test (see table VII). Duncan's test showed that the NMCS means were significantly different among all lateral resupply levels both when OST = 7 days and OST = 15 days.

One test for aptness of the model is to examine residual plots to check for major departures from the assumed model (22:609). A residual analysis was performed to see if there were any gross differences in the error variances for the 12

TABLE VI. ANOVA Table

DEPENDENT VARIABLE: NMCS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	11	1426.54864131	129.68624012	134.38
ERROR	36	34.74380237	0.96510562	PR > F
CORRECTED TOTAL	47	1461.29244368		0.0001

R-SQUARE	C.V.	ROOT MSE	NMCS MEAN
0.976224	7.8069	0.98239789	12.58372994

SOURCE	DF	TYPE I SS	F VALUE	PR > F
LATSUPLY	2	1339.61896564	694.03	0.0001
OST	1	31.25133545	32.38	0.0001
LATSUPLY*OST	2	52.98839650	27.45	0.0001
DEPOT	1	1.19253747	1.24	0.2737
LATSUPLY*DEPOT	2	0.39152221	0.20	0.8173
OST*DEPOT	1	0.72746512	0.75	0.3910
LATSUPLY*OST*DEPOT	2	0.37841893	0.20	0.8228

Table VIIa. Duncan's Multiple Range Test

B=-1

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: NMCS
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=21 MSE=1.18252

NUMBER OF MEANS	2	3
CRITICAL RANGE	1.12931	1.18612

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	A
A	16.7447	8	-1
B	12.5804	8	1
C	5.9901	8	0

Table VIIb. Duncan's Multiple Range Test

B=1

ANALYSIS OF VARIANCE PROCEDURE

DUNCAN'S MULTIPLE RANGE TEST FOR VARIABLE: NMCS
NOTE: THIS TEST CONTROLS THE TYPE I COMPARISONWISE ERROR RATE, NOT THE EXPERIMENTWISE ERROR RATE

ALPHA=.05 DF=21 MSE=0.648506

NUMBER OF MEANS	2	3
CRITICAL RANGE	0.836309	0.878378

MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT.

DUNCAN GROUPING	MEAN	N	A
A	21.2665	8	-1
B	12.6277	8	1
C	6.2029	8	0

treatments. The plot in figure 6 reveals a distribution centered around the 0 reference line with no evident pattern, giving us no reason to reject the model for lack of aptness.

A check of the normality of the error terms was accomplished by preparing a normal probability plot of the residuals against their expected values when the distribution is normal (22:118). If the points fall approximately on a straight line, this suggests that the error terms are approximately normally distributed. An examination of the normal probability plot in figure 7 supports the normality assumption.

Interpretation of Results

The experiment showed that given the model assumptions stated in chapter III, lateral resupply had a significant effect on strategic airlift capability. The significance was evident when OST was varied from 7 days to 15 days, as well as when depot stock level was varied from an unlimited supply to a level equivalent to a WRSK. In addition, the significance remained when the lateral resupply times were all increased by two days. These results provide an affirmative answer to the research question posed in chapter I, "Given a realistic strategic airlift scenario and authorized levels of spare parts, does a policy of lateral resupply significantly increase capability figures?"

When OST was set at 7 days, the mean number of planes NMCS under a policy of no lateral resupply, was 16.7447, which translates into an NMCS rate of 16.7447/38 = 44%. This

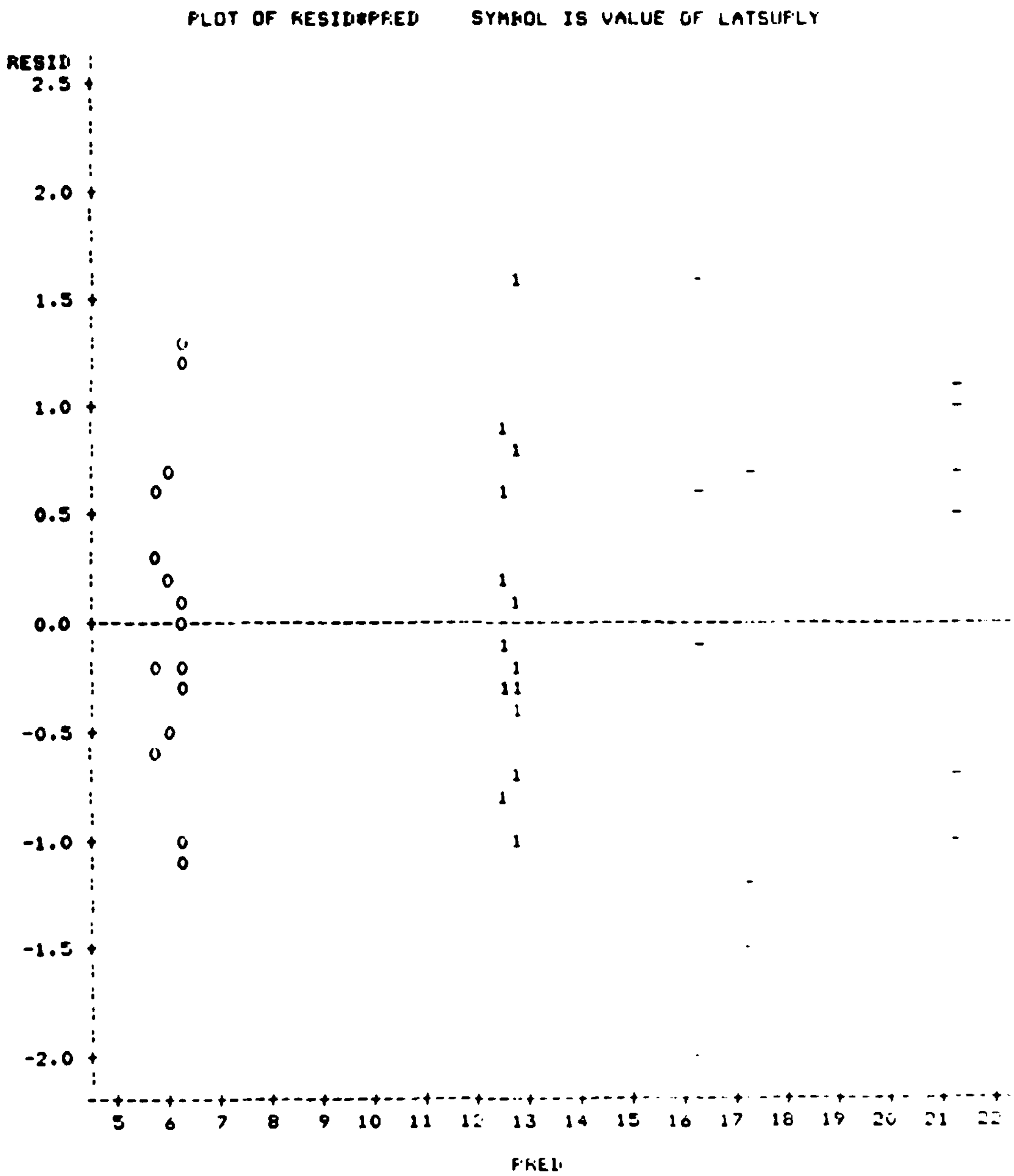

Figure 6. Plot of Residuals

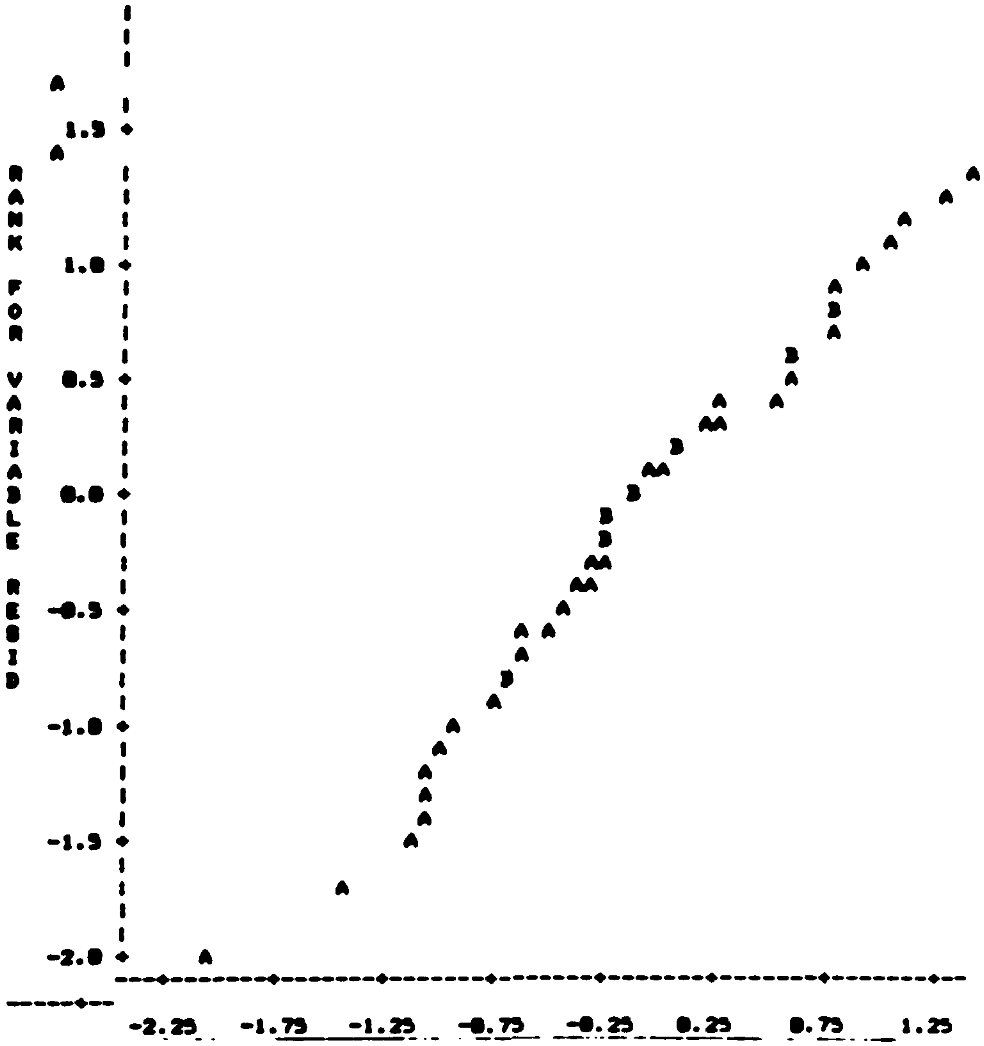

Figure 7. Normal Probability Plot

is the equivalent of saying that during the 30-day scenario, aircraft were FMC 56% of the time. The percentage of aircraft FMC decreased to 44% when OST was increased to 15 days. Similar calculations were made for the two lateral resupply options. The results are summarized in Table VIII.

Table VIII.
Percentage of Planes FMC

	OST	
	7 DAYS	15 DAYS
NO LATERAL RESUPPLY	56%	44%
LATERAL RESUPPLY (AD= 1 DAY)	84.2%	83.7%
LATERAL RESUPPLY (AD= 3 DAYS)	66.9%	66.7%

The change in OST had a considerable effect on FMC rates when no lateral resupply was performed, and virtually no effect when lateral resupply was used. This is because without lateral resupply, a base out of stock for a part must wait for the OST to elapse before the plane can be fixed. In contrast, under a lateral resupply policy, when base stock could not supply the part, most demands were satisfied by lateral shipments from neighboring bases. As lateral shipping times approach OSTs, the significance of a lateral resupply policy diminishes.

If cannibalization procedures had been utilized, FMC rates would hopefully have increased. This would affect all treatments, but would have the greatest impact on the treatments with no lateral resupply, since those broken planes could possibly be repaired the same day, as opposed to

waiting 7 or 15 days for a part from the depot. The problem with incorporating cannibalization in a simulation is that a specific rule must be followed so a determination can made as to whether a part should be canned under a certain condition. For instance, one possible rule would be that if a plane was NMCS at a base, and not expecting a demand to be satisfied for three days or more, that plane would be subject to cannibalization.

An additional problem with modeling cannibalization is that parts sometimes break when they are removed from one aircraft and put on another. This problem would need to researched to the extent that probabilities could be assigned for each part's susceptibility of breaking during a cannibalization. In the field, the maintenance officer makes the decision to can a part from an available plane, an action usually reserved as a last resort (32:17).

Summary

This chapter took an extensive look at the results of the experiment, and interpreted those results in the context of the first research question. An analysis of the SLAM model outputs confirmed the validity of the model, and an analysis of the experimental results provided the answer to the first research question. The second research question will be addressed in the concluding chapter.

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